UTILIZING CITIZEN SCIENCE TO ASSESS BIRD COMMUNITY COMPOSITION WITHIN A CHANGING MARSH-MANGROVE ECOTONE IN TEXAS

A Thesis

by

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ABSTRACT

Climate change is likely to drive large geographic species shifts such as woody encroachment into grassland ecosystems. Along the Gulf of Mexico, this shift manifests as a change from grass-dominated salt marshes to woody black mangrove stands. Such changes are likely to affect the multidimensional habitat space that birds rely on, but how bird communities will respond to this shift is poorly understood. This study utilized citizen scientist observations to provide an initial assessment of how bird community compositions differ within a mangrove-marsh ecotone in Texas. Citizen science, the public's involvement in data collection, can allow ecologists to feasibly investigate larger spatial and temporal patterns than otherwise possible. We overlaid observations of wading, shorebird and passerine assemblages from Cornell's Lab of Ornithology's eBird database onto vegetation distribution maps in ArcGIS. We designated study sites by using spatial analysis tools and assessed bird use of mangrove and marsh sites in the central (San Patricio and Nueces counties) and lower (Cameron county) regions of Texas.

Bird use significantly differed between mangroves and marshes, but general patterns of use varied amongst study regions. Marshes in the central region supported significantly more bird species and higher abundances than mangrove sites. Lower region marshes had significantly higher bird species diversity per sampling event. Bird assemblages were dissimilar, with some species overlap between central region marshes and mangrove communities. Waders were common in all vegetation types and regions, but wader abundances were somewhat higher in marshes than in mangroves in the central region. In general, larger abundances of shorebirds were observed at either region's marsh sites than mangroves. Passerines species generally targeted by birdwatchers, such as migratory warblers, were only observed at marsh sites in the central region. Overall, these results suggest that a shift in the marsh-mangrove ecotone along coastal Texas affects bird community compositions. This initial assessment will enhance the ability of scientists and policymakers to shape coastal management strategies that protect vital habitat for bird communities under climate change scenarios.

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1. INTRODUCTION

Unprecedented rates of climate change have contributed to large geographic shifts in species distributions (Walther et al. 2002, Parmesan and Yohe 2003, Root et al. 2003). One type of species shift, woody encroachment into grassland ecosystems, has become a global phenomenon (Knapp et al. 2008, Eldridge et al. 2011). Across many subtropical coastal ecosystems, this shift manifests as a change from short-stature grasslands (salt marshes) to medium-stature forests (mangroves) (Saintilan et al. 2014). In North America, a mangrove species, *Avicennia germinans,* has expanded at its northern-most range on the east coast of Florida (Cavanaugh et al. 2014) and has increased in area along the northern Gulf of Mexico coastline (Stevens et al. 2006, Perry and Mendelssohn 2009, Everitt et al. 2010). A variety of climate factors influence mangrove distributions, such as sea-level rise, sea-surface temperatures, aridity, and atmospheric CO_2 concentrations (Saintilan et al. 2009, McKee et al. 2012, Quisthoudt et al. 2012). However, mangrove stand expansion in North America is largely attributed to a decreasing frequency and severity of winter freezing events (Osland et al. 2013, Cavanaugh et al. 2014, Cavanaugh et al. 2015). Though mangroves are susceptible to freeze-induced xylem embolism (Stuart et al. 2007), phenotypic plasticity has been observed in Texas black mangroves (*A. germinans*) whose narrower vessels may contribute to mangrove survival following short-duration freeze events (Madrid et al. 2014). The last substantial diebacks of black mangrove populations in Texas occurred during December of 1983 and 1989 (Sherrod and McMillan 1985, Lonard and Judd 1991, Everitt et al. 1996). Climatic models report a 95% probability of warmer Texas winters (Nielsen-Gammon 2011), which will likely increase mangrove prevalence across the state's coastline (Montagna et al. 2007). Furthermore, a 2-4°C increase in mean annual minimum temperature could result in mangrove displacement of salt marshes across the entire Texas coastline by the year 2100 (Osland et al. 2013). Already, black mangrove stand areas have increased in area by 74% across Texas in just 20 years (1990 to 2010) (Armitage et al. 2015).

A change in foundation species, from a marsh to mangrove dominated coastline, will likely have substantial impacts on local ecosystem functions (Ellison et al. 2005). How the existing Texas coastal ecosystem will respond to this shift in marsh-mangrove dominance is not well understood, particularly for migratory and resident birds. The difference in vegetation structure between short stature marshes and the taller, more structurally complex canopies of mangrove stands will likely affect the multidimensional habitat spaces that bird communities rely on. Vegetation structure complexity has widely been recognized as a factor in migratory bird distributions and community structure across large biogeographic scales (MacArthur and MacArthur 1961, MacArthur et al. 1966, Willson 1974, Rotenberry 1985, Deppe and Rotenberry 2008). Globally, increasing woody plant dominance of terrestrial grassland biomes has shifted prominent feeding guilds (Wilson et al. 2014), decreased occurrence of grassland obligate species (Grant et al. 2004), and altered bird community compositions (Skowno and Bond 2003, Chapman et al. 2004, Sirami and Monadjem 2012). However, there has been no previous work on the impacts of woody encroachment on coastal bird communities. Therefore, my thesis investigates differences in bird community assemblages between black mangrove stands and salt marshes in Texas.

Understanding the effects of mangrove encroachment into Texas salt marshes is important for the scientists and policy makers that are tasked with shaping coastal management strategies. Coastal Texas is part of the Central Flyway, a large avian migratory corridor, and is used by circum- and trans-gulf migrants that depend on quality stopover habitat. Among these migrants is the critically endangered Whooping Crane (*Grus americana*). Whooping Crane winter territory lies within the Aransas and Matagorda Island National Wildlife Refuges, which are also “hot spots” of mangrove expansion on the Texas coast (Montagna et al. 2007, Chavez-Ramirez and Wehtje 2012, Armitage et al. 2015). Whooping crane breeding pairs maintain high territory fidelity and are unlikely to utilize areas where black mangroves are present (Chavez-Ramirez and Wehtje 2012). The structural complexity of black mangrove canopies could limit accessibility to one of the crane's primary winter food sources, blue crabs (*Callinectes sapidus*). In addition, black mangroves produce many pneumatophores (protruding aerial roots) into shallow water flats, which could limit wading bird foraging efficiency (Meyerriecks 1971) (Figure 1). Additionally, grassland-specialists could lose suitable nesting habitat; Seaside Sparrows (*Ammodramus maritimus*) use smooth cordgrass (*Spartina alterniflora*) to support and weave nests (Gjerdrum et al. 2005). However, marsh specialists may adapt to marsh-mangrove mixed habitats. Texas Seaside Sparrows (*Ammodramus maritimus sennetti*) nests have been found in black mangrove canopies, but these nests were composed primarily of woven salt marsh grasses (Phillips et al. 2003, Ubias et al. 2013). Overall, increasing dominance of black mangroves along the

Texas coastline will likely affect local bird habitat use and therefore alter community compositions.

Figure 1. Black mangrove production of aerial root structures called pneumatophores may alter microhabitat features in salt marshes.

Changing bird assemblages could impact coastal ecosystem services such as bird watching. Recognized as a North American "hot spot" for migratory and resident birds, over 400 bird species occur along the Texas coastline (Mathis and Matisoff 2004, Jones et al. 2008). A decline in iconic coastal birds or a decrease in species richness could have negative effects on a lucrative ecotourism industry (Sekercioglu 2002); the Rio Grande

Valley Birding Festival in lower Texas is estimated to have a $1.5 million annual total gross output (Mathis and Matisoff 2004). The Great Texas Coastal Birding Trail, wildlife refuges, various bird festivals, and local Audubon chapter bird counts attract birders from across the nation and world and fosters an active community of resident birdwatchers. In general, birdwatchers are well-educated, affluent, goal driven, and environmentally conscious (Cordell and Herbert 2002, Sekercioglu 2002). The overall culture birdwatchers uphold make them ideal participants in citizen science programs.

Citizen science projects are characterized by the engagement of volunteers in data collection and have been in use for decades. For example, the Breeding Bird Survey (BBS) was initiated in 1965 and the Christmas Bird Count (CBC) was founded in 1900 (Butcher et al. 1990, Dickinson et al. 2010). In 2002, the Cornell Lab of Ornithology and National Audubon Society launched eBird, an online citizen science database for birdwatchers to upload their checklists. Unlike the BBS and CBC 1-day counts at predetermined sites (Butcher et al. 1990), eBird protocols accommodate sampling events from any location or time of the volunteer's choosing (Sullivan et al. 2009). Since its commencement, there has been a 30-40% annual increase in the volume of data contributed to this crowd-sourced database (Sullivan et al. 2014).

Certain caveats and biases are associated with this citizen science dataset. Data quality is managed by filtering entries through an automated system which flags potentially erroneous entries based on species counts, season and geographic area; flagged entries are reviewed by regional experts (Bonney et al. 2009, Sullivan et al. 2009, Wood et al. 2011, Sullivan et al. 2014). However, sampling events are concentrated in highly populated regions (i.e., cities and suburbs) (Munson et al. 2010), cryptic species are not as frequently detected and reported, and amateur birdwatchers may misidentify species (Sullivan et al. 2009). Nevertheless, the eBird dataset has spatial and temporal breadth that cannot be achieved by individual observers. Therefore, it is an ideal resource to address my question about bird use of mangrove and salt marsh habitats along the Texas coastline.

My objective was to determine if bird community assemblages differed between black mangrove stands and salt marshes within the marsh-mangrove ecotone in Texas. I utilized observations from eBird, an online crowd-sourced citizen science database to quantify estimated bird species richness, abundance, Simpson's diversity index, and similarity between black mangrove and salt marsh bird assemblages. Observations from eBird were overlaid on vegetation distribution maps derived from Landsat imagery to compare bird community composition between vegetation types. I hypothesized that marshes would support more bird species, larger abundances, and a more diverse bird community than mangrove sites. Furthermore, I hypothesized that the composition of wading, shorebird, and passerine assemblages would be dissimilar between marshes and mangroves. Specifically, I expected fewer wading and shorebirds would be found in black mangrove areas than in salt marshes.

2. METHODS

2.1 Citizen Science Dataset

I analyzed 2010 eBird observations (eBird Basic Dataset Version: EBD_relFeb-2014) that corresponded with available 2010 vegetation distribution maps. I only included sampling events that met the following quality control criteria: a specific GPS coordinate was reported, all bird species detected were reported, the entry was not flagged by a reviewer, and the area or distance covered was within a 100 m radius of the reported GPS coordinates. For incidences where birdwatcher groups reported sampling events individually rather than collectively, I removed repeated reports based on group identification number. I focused on bird species that could be grouped into wading (Ardeidae, Threskiornithidae, Ciconiiformes), shorebird (Recurvirostridae, Haematopodidae, Charadriidae, Scolopacidae), or passerine (Passeriformes) assemblages. I created these assemblages to reflect groups of bird species with similar morphology and foraging behavior. For example, wading birds are large, long-legged birds that wade in water while foraging. I excluded Whooping Cranes because there was a disproportionately large number of observations from a very small endangered population residing in the Aransas National Wildlife Refuge. I also excluded passerines identified as insectivore air screeners (e.g., swallows and martins) (De Graaf et al. 1985) because eBird survey methods would not be appropriate for studying their association with wetland vegetation (Bibby 2000). Though birds in the family Rallidae are known marsh dependents in the Gulf of Mexico, they were excluded due to their inconspicuous behavior that necessitate call back survey sampling methods for accurate density assessments (Conway 2011).

2.2 Coastal Vegetation Distribution Map

I acquired a 2010 Texas coastal vegetation distribution map created from a previous study that conducted supervised classifications of Landsat 5 Thematic Mapper (TM) imagery (Armitage et al. 2015). Armitage et al. (2015) classified imagery by using Artificial Neural Networks (ANNs) in the software program ENVI 4.8 (Exelis Visual Information Solutions Boulder, CO) which utilized information from Tasseled Cap bands and training data from ground truth sites and National Agriculture Imagery Program's (NAPI) 2010 Digital Orthophoto Quarter Quads. Land cover classifications included mangrove, salt marsh, bare/fallow land, beach, forest, tidal flats, urban, pasture/grassland/shrub, other wetland (primarily non-tidal grasses and forbs), and open water. The study's 2010 Texas coastal vegetation distribution map had an overall classification accuracy of 69.0% (kappa coefficient = 0.66). However, salt marsh and mangrove land cover classes had higher individual classification accuracies. Salt marsh classification had a total accuracy of 89.0% (conditional kappa = 0.73), user accuracy of 89.0% (error of inclusion), and producer accuracy of 66.4% (error of exclusion). Black mangrove classification had a total accuracy of 81.0% (conditional kappa = 0.79), user accuracy of 81.0%, and producer accuracy of 98.8%. One limitation of using medium resolution (30 m) satellite imagery is that individual mangroves that are sparsely distributed within a marsh may not be detected. However, using the TM imagery is appropriate for my study objective, since I am interested in the difference in bird communities between expanses of marsh or mangrove stands rather than alterations at a fine vegetation compositional scale.

2.3 Spatial Analysis

Using geospatial analysis tools in ArcGIS 10.3 (ESRI 2014), I calculated the coverage of various land cover classes within a 100 m radius buffer encircling the bird sampling events that met the aforementioned criteria (Figure 2). I used a binary approach to designate sites as mangrove or salt marsh (hereafter referred to as marsh) in my analyses. I defined marsh sites as buffer zone areas where marsh was present but no mangrove coverage was detected with remote sensing imagery classification (Osland et al. 2013). If the mangrove land cover class was detected within the buffer zone, then the site was classified as a mangrove site regardless if marsh was also present. From personal field observations, marshes adjacent to dense mangrove stands commonly have individual mangrove shrubs sparsely distributed throughout. Due to a limited number of samples, sites dominated by mangroves as well as sites that were a mix between mangrove and marsh were grouped together in my analyses. None of the buffer zones were comprised solely of just marsh or mangrove; other vegetation types such as non-tidally influenced wetland and paved roads were encompassed in the buffer zone ('other wetland' and 'urban' land cover classes). However, all sites contained at least 900 m^2 of wetland vegetation.

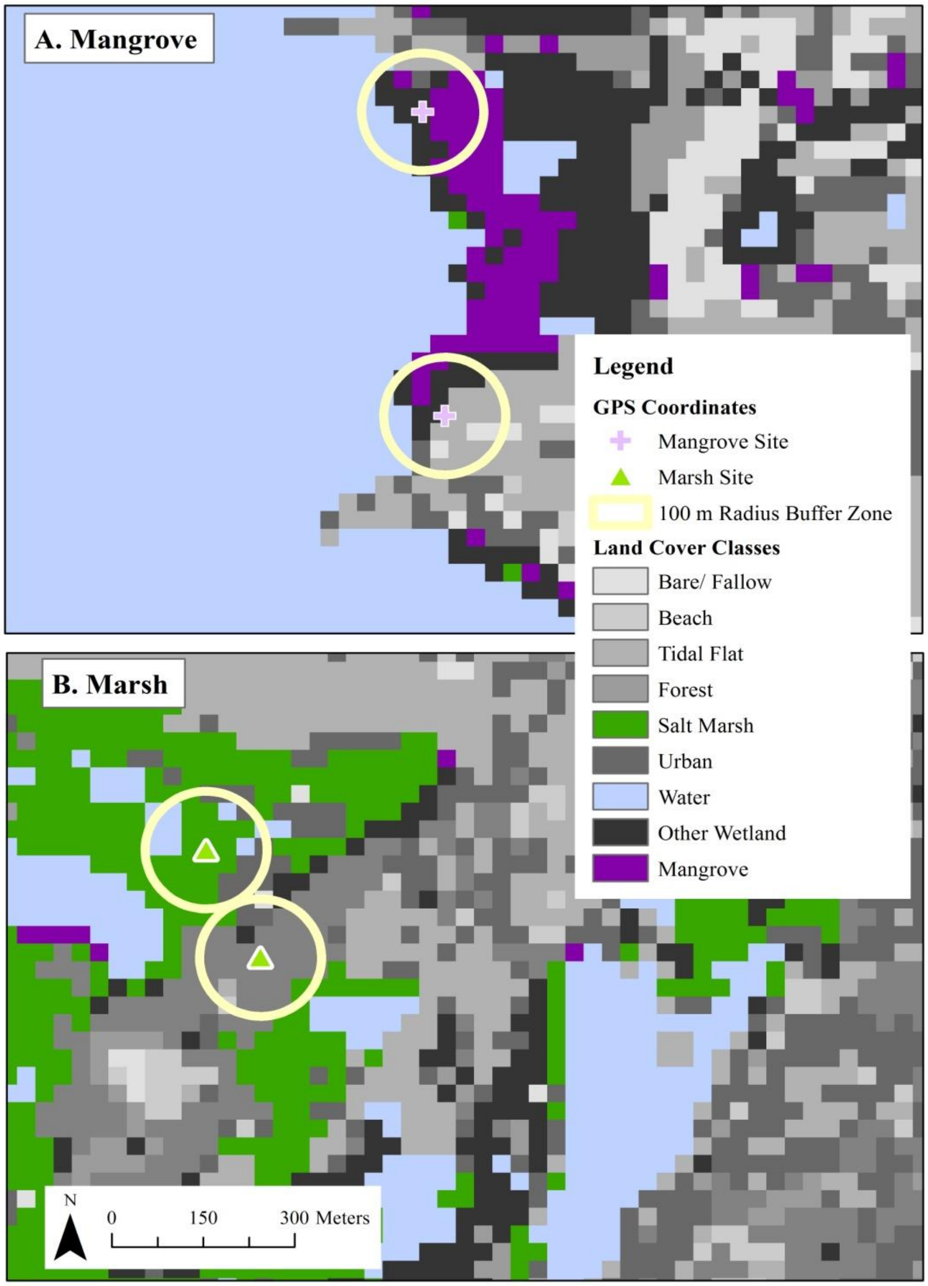

Figure 2. Illustrative examples of the 100 m radius buffers that were used to calculate the composition of land cover types surrounding each (A) mangrove and (B) marsh sampling event location.

2.4 Data Analysis

Both mangrove and marsh sites were present in three counties: San Patricio and Nueces on the central coast, and the southernmost Texas county, Cameron (Figure 3). These counties are the areas in Texas with the highest cover of mangrove stands. Cameron county receives less rainfall (Nielsen-Gammon 2011, Osland et al. 2014), is more arid (Osland et al. 2014), and has a warmer winter minimum temperature than San Patricio and Nueces counties (Nielsen-Gammon 2011, Osland et al. 2013). Due to this climatic gradient across the coastline, I separated the counties into a central region (San Patricio and Nueces) and lower region (Cameron) for data analyses.

Contributors to eBird have the option to either report that a species was present or provide a count for each individual bird species observed. Sampling event data was therefore compiled into separate datasets for species richness and another for abundance and species diversity analyses. Each of these datasets were comprised of data collected from four types of eBird protocols (Casual Observation, Stationary Count, Exhaustive Area Count, and Traveling Count). Protocols were grouped together due to a limited number of sampling events that met aforementioned criteria (Appendix Table A-1). Stationary, Exhaustive, and Traveling sampling events were included in my analyses only if they were constrained within the limits of the 100 m buffer zone. Casual Observations were assumed to occur within the limits of the buffer zone based on the

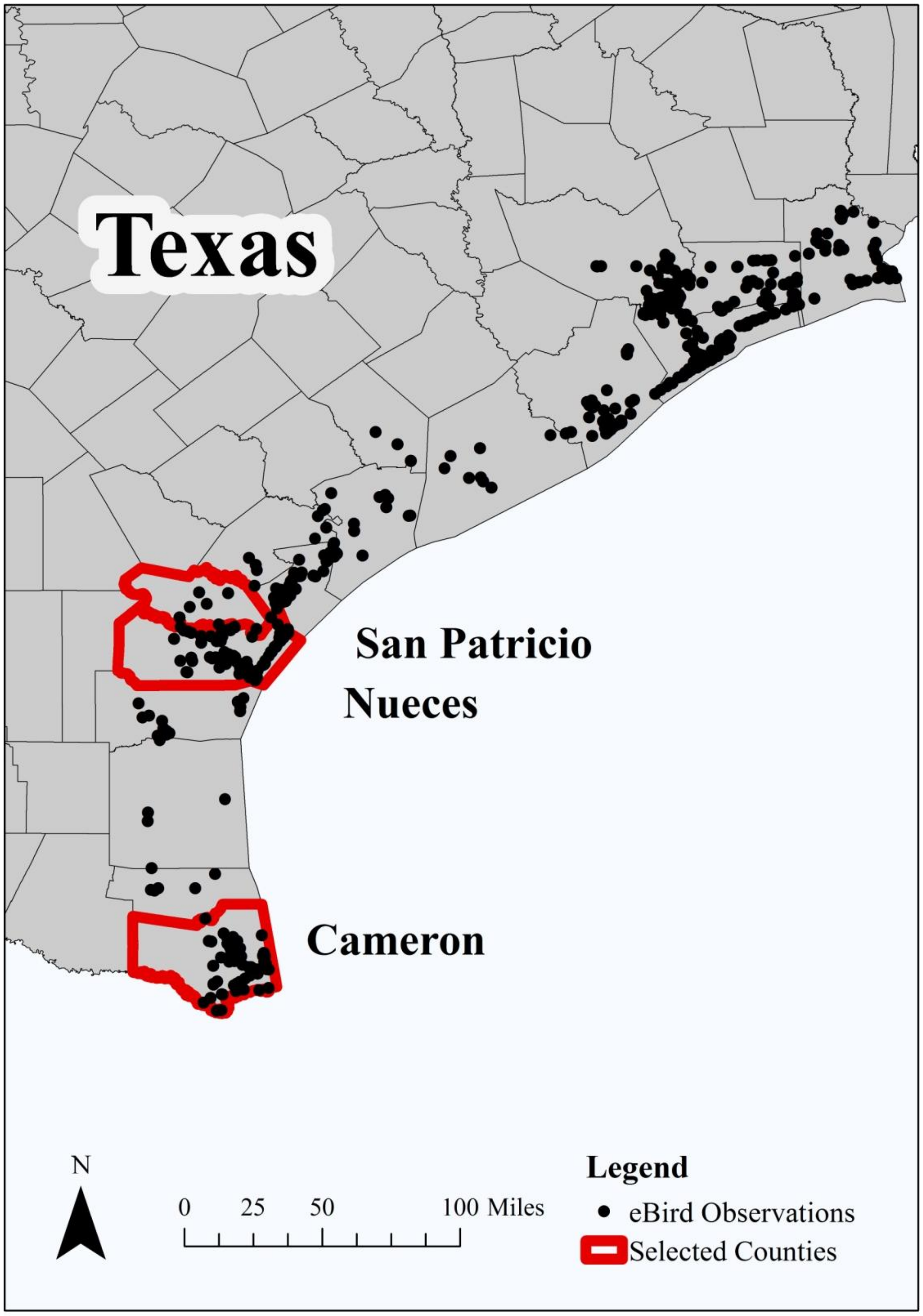

Figure 3. County map of coastal Texas depicting the distribution of eBird sampling events. A combination of both mangrove and marsh observations only occurred in San Patricio, Nueces, and Cameron counties.

eBird definition of this protocol as an incidental sighting (e.g. spotting a bird in backyard while gardening). Additionally, each Casual Observation event was assumed to last for 10 minutes; all other eBird protocols required birdwatchers to report the duration of their observation (Appendix Table A-1). No individual sampling event lasted longer than 60 minutes. The cumulative duration of time spent observing birds were relatively equal between each study region's vegetation types (Appendix Tables A-2 and A-3). I did not investigate seasonal patterns because there were a limited and unequal number of sampling events across vegetation types and seasons (Appendix Tables A-2 and A-3). Data were pooled across the entire calendar year (2010) in order to achieve adequate statistical power for analyses.

Species Richness

The species richness dataset was an aggregation of sampling events where a birdwatcher reported the presence/ absence or a count of each bird species. In the central region, sampling events were distributed across two mangrove sites and five marsh sites (Figure 4, Appendix Table A-2). In the lower region, mangrove sampling events occurred across ten sites and marsh sampling events occurred across six sites (Figure 4, Appendix Table A-2). In the central region, there were many more sampling events at marsh sites ($n = 125$) than at mangrove sites ($n = 16$). Using G*Power 3.1.9 (Faul et al. 2007), I determined the necessary number of subsamples to maintain at least 80% power (1- ß) with known effect size, allocation ratio, and given alpha ($\alpha = 0.05$). Following this

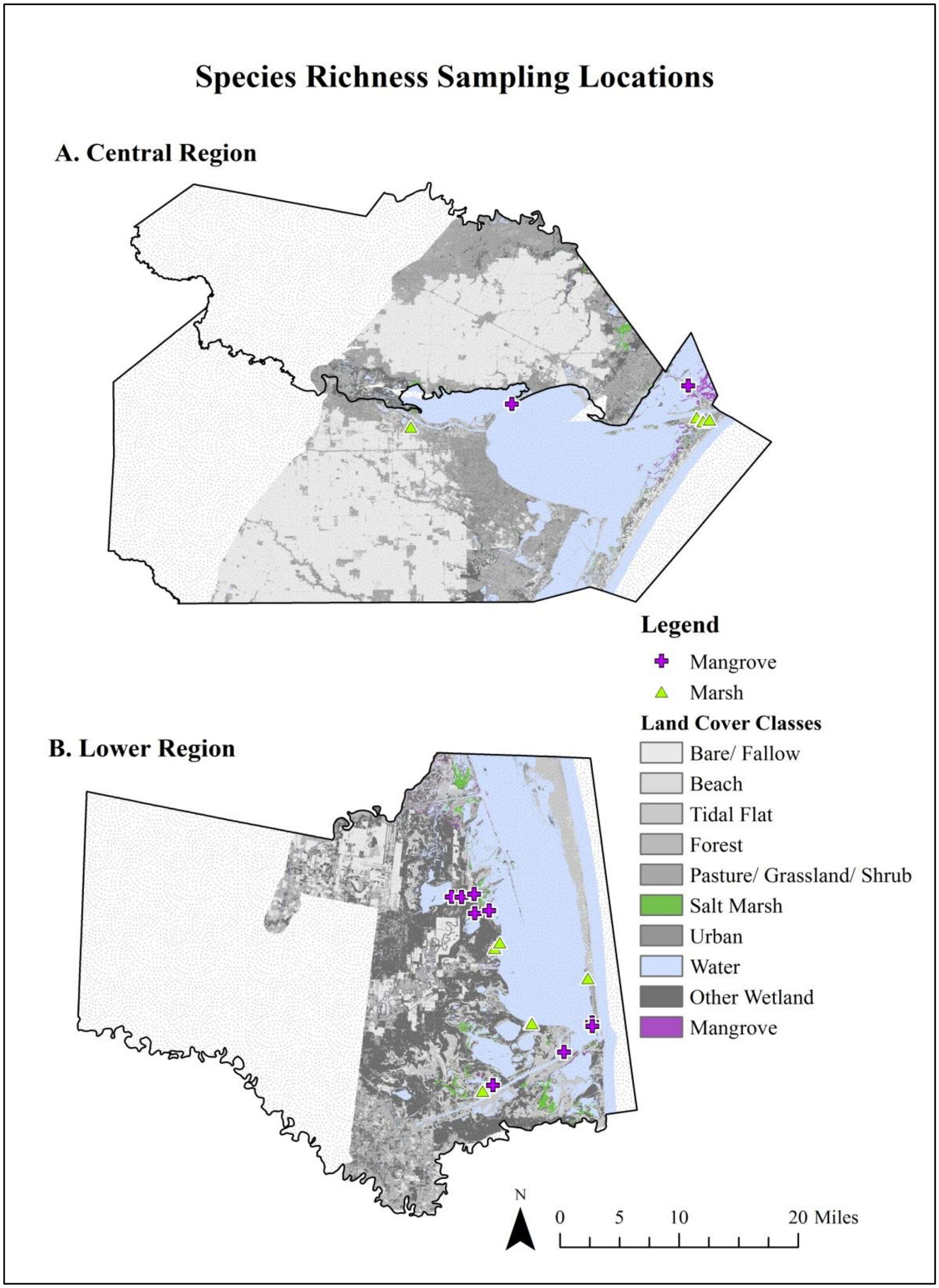

Figure 4. Locations of sampling events for species richness data within the (A) central and (B) lower region counties.

analysis, I randomly selected a subset of 20 sampling events at marsh sites in the central region for my species richness analyses (Appendix Table A-2). This adjustment was not necessary in the lower region, which had a more even distribution of marsh (n = 14) and mangrove (n = 11) sampling events (Appendix A-2).

Statistical analyses were performed using R Statistical Software (Team 2013). I first conducted a diagnostic Shapiro-Wilk test on all sampling events, which revealed that species richness data were not normally distributed. Therefore, I proceeded to test whether there was a difference in species richness between vegetation types using a permutation test with 1000 randomizations without replacement and alpha = 0.05 (Quinn and Keough 2002). Permutation tests resample the original data to generate a sampling distribution. A low p-value (< 0.05) indicates that random arrangements of data are not as equally probable as the collected original data (Crowley 1992, Quinn and Keough 2002). I used the following equation to calculate the percent frequency of occurrence for each bird species.

$$\text{Percent frequency of occurrence} = \left(\frac{x_{\mathrm{i}}}{\mathrm{X}}\right) \times 100$$

$x_{\mathrm{i}} = \text{the number of sampling events where a particular species was observed}$

$\mathrm{X} = \text{the total number of sampling events in a region's vegetation type}$

Since the number of species richness sampling events were limited, I plotted a sequential sample size analysis for each region's vegetation type in order to visualize if the means stabilized at an asymptote (Morrison 2009). If the permutation test was not significant, then I used sequential sample size analysis to determine whether there may have been too few sampling events at a particular region's vegetation type.

Abundance and Simpson's Diversity Index

The abundance and Simpson's diversity index dataset is comprised solely of sampling events where birdwatchers counted the number of individuals per species. In the central region, mangrove sampling events (n = 12) occurred at two sites and marsh sampling events (n = 16) occurred across five sites (Figure 5, Appendix Table A-3). In the lower region, mangrove sampling events (n = 11) occurred across nine sites and marsh sampling events (n = 9) occurred across six sites (Figure 5, Appendix Table A-3).

Statistical analyses were performed using R Statistical Software (Team 2013). According to a Shapiro-Wilk test, the abundance data were not normally distributed. Therefore, I proceeded to test whether there was a difference in abundances between vegetation types using a permutation test with 1000 randomizations without replacement and alpha = 0.05 (Quinn and Keough 2002). I used the following equation to calculate Simpson's diversity index.

$$\text{Simpson's diversity index} = 1 - \left(\sum \left(\frac{n_i}{N}\right)\right)^2$$

n_i = total number of organisms of a particular species

N = total number of organisms of all species

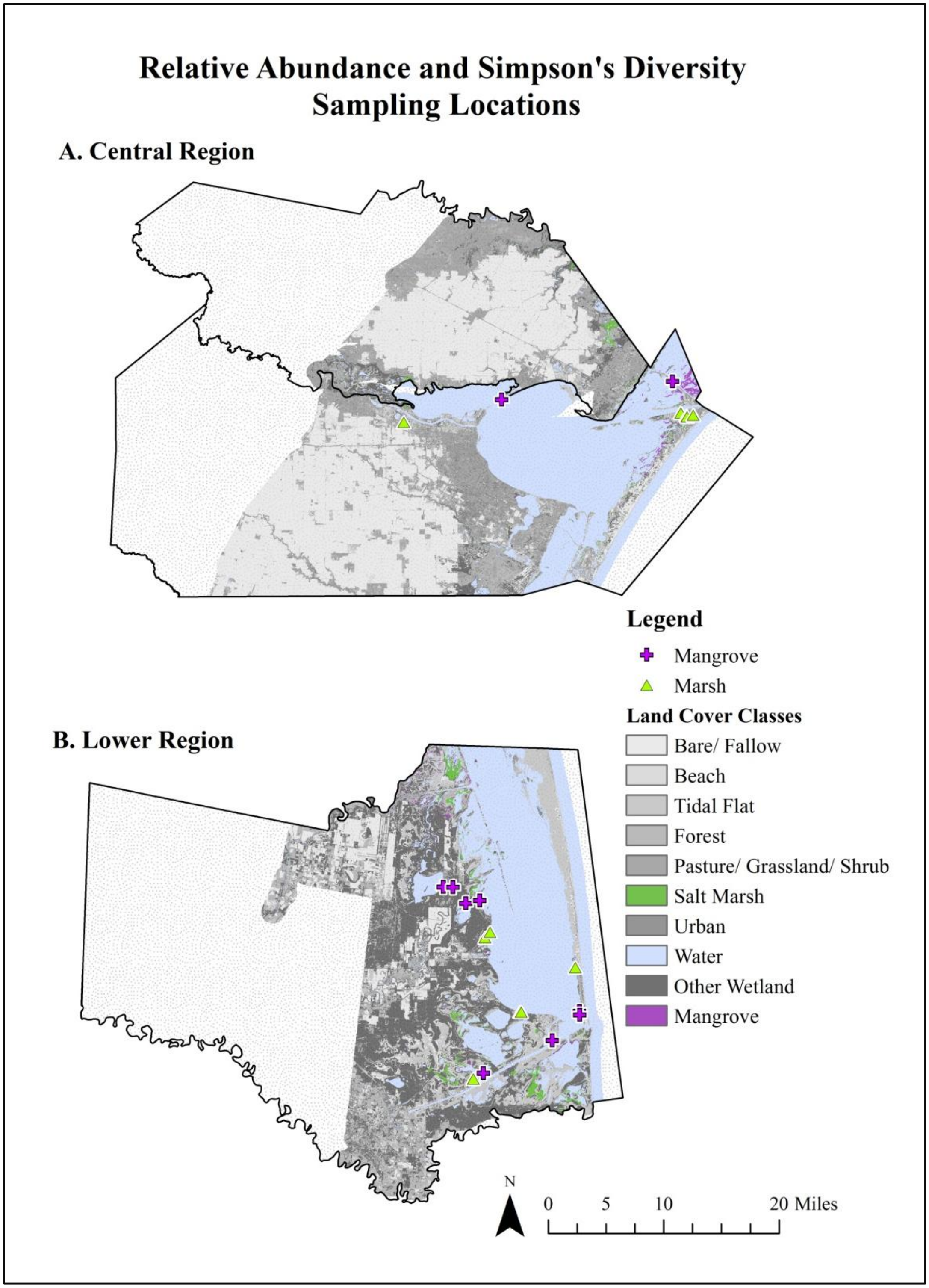

Figure 5. Locations of sampling events for relative abundance and Simpson's Diversity Index data within the (A) central and (B) lower region counties.

Species diversity data were not normally distributed, therefore I used a permutation test with 1000 randomizations without replacement and alpha = 0.05. For abundance and Simpson's diversity index analyses, I plotted a sequential sample size analysis for each region's vegetation type, in order to visualize if the total number of sampling event's mean stabilized at an asymptote (Morrison 2009). If the permutation test was not significant, then I used sequential sample size analysis to determine whether there may have been too few sampling events at a particular region's vegetation type.

Bird Community Composition

To determine dissimilarities in bird community composition between vegetation types within each region, I used a multivariate analysis called Analysis of Similarity (ANOSIM), based on a log transformed Bray-Curtis resemblance matrix in PRIMER v7 (Clarke 1993, Clark and Gorley 2015). Specifically, I tested for the dissimilarity between individual species assemblages as well as grouped assemblages (wading, shorebird, and passerine) of each study region's vegetation type. Analogous to an Analysis of Variance (ANOVA), an ANOSIM uses a permutation procedure applied to similarity matrix to measure the average dissimilarity within and between group factors (Clarke and Warwick 1994, Quinn and Keough 2002). Non-parametric analyses, such as ANOSIM, are ideal for analyzing my data, which are not normally distributed, have high variance, and have unequal sample sizes between vegetation types. A ANOSIM global R static that is less than 0.25 indicates a substantial amount of overlap between assemblages, a value between 0.25 to 0.5 indicates that assemblages are distinct but have some overlap, and a value greater than 0.5 indicate highly dissimilar assemblages. Furthermore, I used nonmetric, multidimensional scaling (nMDS) ordination to visualize dissimilarities between communities in mangroves and marsh vegetation types within each region. I used Similarity Percentages (SIMPER) as an exploratory tool to identify which bird species and grouped assemblages contributed the most to the dissimilarity in the nMDS ordination.

3. RESULTS

3.1 Species Richness

Over the 36 sampling events (marsh = 20, mangrove = 16) in the central study region, birdwatchers observed a total of 89 bird species. In this region, species richness was significantly lower in mangrove sites than in marshes ($p = 0.001$, Figure 6). At marsh sites, birds were distributed equally among the wading, shorebird, and passerine assemblages (Figure 7). In contrast, at mangrove sites, passerines comprised only ~10% of the observed species per sampling event; shorebirds and waders accounted for 40-47% of the observations (Figure 7). A total of 11 wading bird species were observed in mangroves and 14 species were observed in marshes; frequently reported wading bird species in both vegetation types included Great Blue Herons (marsh = 65%, mangrove = 31.3%) and Great Egrets (marsh = 55%, mangrove = 31.3%) (Appendix Table A-4). Roseate Spoonbills and White Ibises, wading species that forage by using their bill to strain or probe, were more frequently reported in marshes (60%, 50%) than in mangroves (25%, 25%) (Appendix Table A-4). In mangroves, the most frequently observed wading species were Reddish Egrets (50%), Great Blue Herons, Great Egrets, and Snowy Egrets (31.3%), which use their bill to strike prey (Appendix Table A-4). A total of 19 shorebird species were observed in mangroves and 28 species were observed in marshes. The most frequently reported shorebird species in marshes were Black-necked Stilts (60%) and Willets (45%); in mangroves the most frequently reported species were Black-bellied Plovers (37.5%) and Willets (56.3%) (Appendix Table A-4). A total of five passerine species were observed in mangroves and 43 species were observed in marshes; the most frequently reported passerine species in both vegetation types were Great-tailed Grackles (marsh = 50%, mangrove = 37.5%) and Red-winged Blackbirds (marsh = 45%, mangrove = 12.5%) (Appendix Table A-4). Several warbler species, such as American Redstart and Yellow Warbler, and marsh-dependent species, such as Marsh Wren and Swamp Sparrow were observed only within marsh sites (Appendix Table A-4).

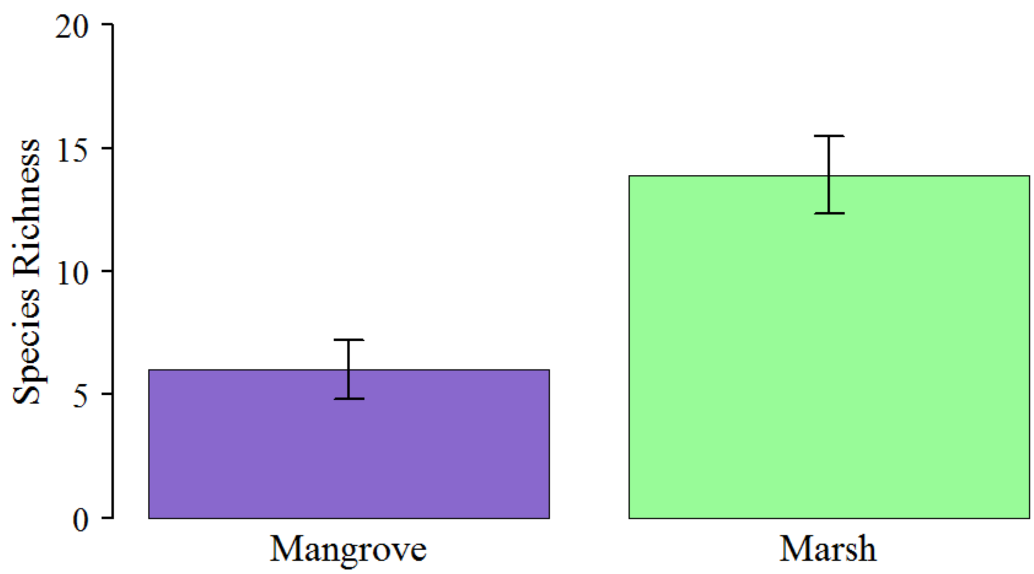

Figure 6. Bird species richness (average ± standard error) per sampling event at mangrove and marsh sites in the central study region.

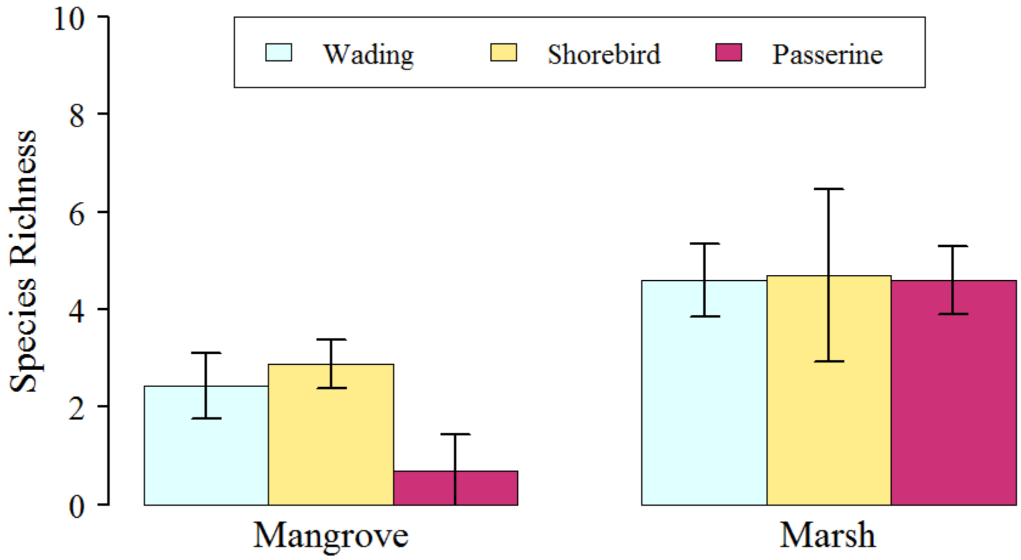

Figure 7. Number of bird species in wading, shorebird, and passerine assemblages (average ± standard error) per sampling event at mangrove and marsh sites in the central study region.

In the lower study region, birdwatchers reported at total of 60 bird species during 25 sampling events (marsh = 11, mangrove = 14). There was a marginally non-significant difference between the number of bird species recorded in marsh or mangrove sites ($p = 0.055$). There was a considerably lower average species richness in mangroves than marshes (Figure 8). A non-significant difference may have been driven by high variability among the smaller number of marsh sampling events ($n = 11$, Figure 9D). At marsh sites, wading and shorebird assemblages comprised the majority of the observed birds per sampling event; bird species present in mangrove sites were predominately waders (Figure 10). A total of 12 wading bird species were observed in mangroves and 11 species were observed in marshes; the most frequently reported wading bird species in both vegetation types were Great Blue Herons (marsh = 72.7%, mangrove = 42.9%), Great Egrets (marsh = 63.6%, mangrove = 42.9%), and Snowy Egrets (marsh = 63.6%, mangrove = 28.6%) (Appendix Table A-4). A total of 11 shorebird species were observed in mangroves and 23 species were observed in marshes; the most frequently reported shorebird for both vegetation types was the Willet (marsh = 63.6%, mangrove = 14.3%) (Appendix Table A-4). Black-bellied Plovers (54.5%) and Ruddy Turnstones (45.5%) were also frequently observed in marshes (Appendix Table A-4). A total of 17 passerine species were observed in mangroves and eight species were observed in marshes. The most frequently reported passerine in both vegetation types were Great-tailed Grackles (marsh = 36.4%, mangrove = 21.4%) (Appendix Table A-4). Though more passerine species were observed throughout all mangrove sampling events than marshes, many of these species were only reported once.

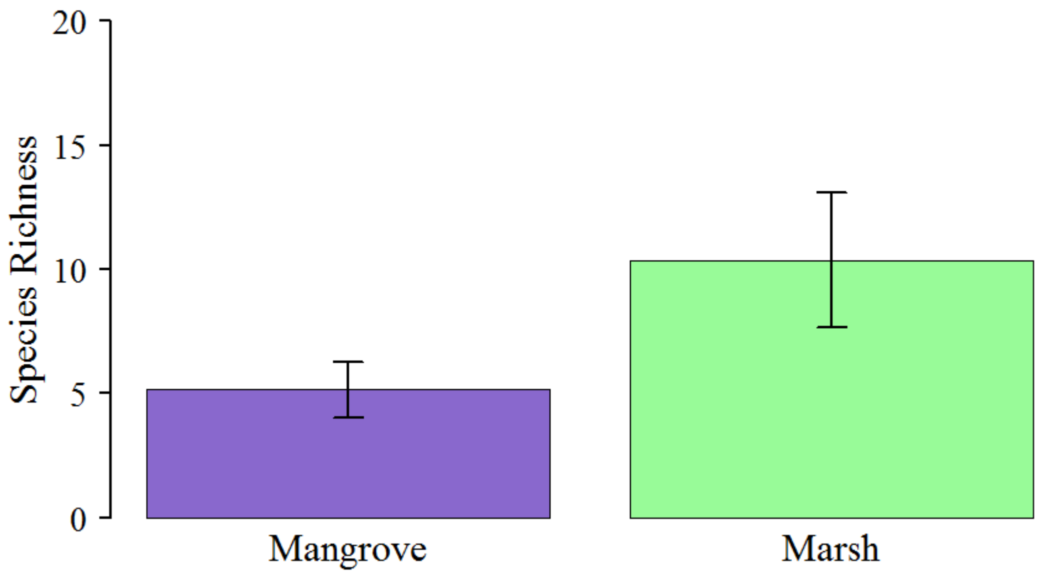

Figure 8. Bird species richness (average ± standard error) per sampling event at mangrove and marsh sites in the lower study region.

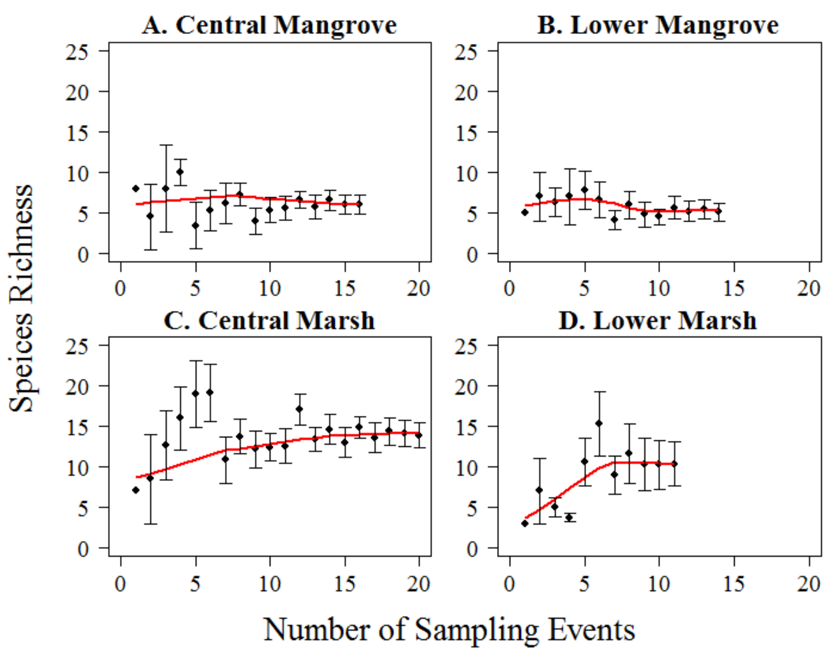

Figure 9. Sequential sample size analyses depicting the stability across the total number of bird species richness sampling events (average ± standard error) for (A and C) central and (B and D) lower regions.

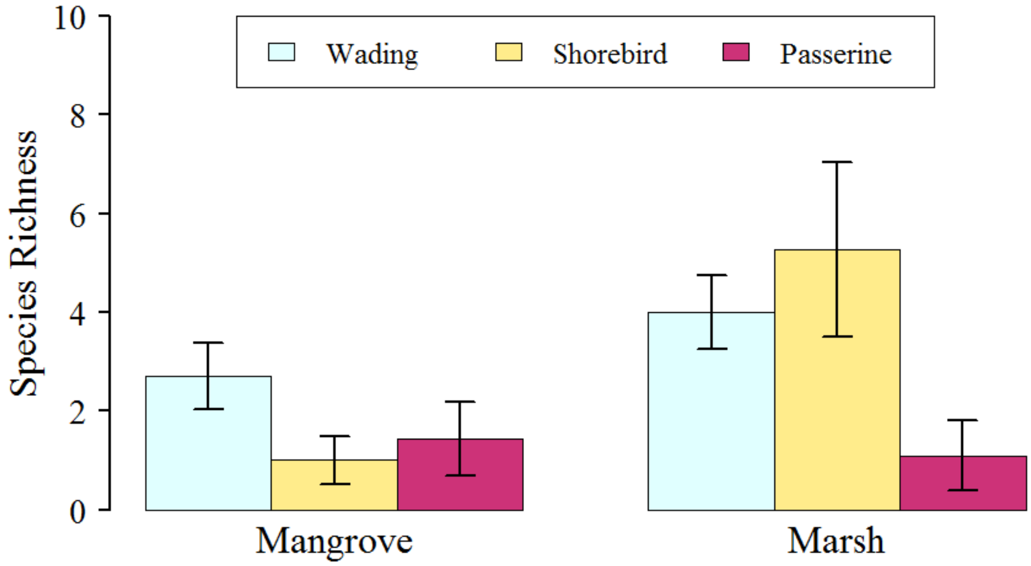

Figure 10. Number of bird species in wading, shorebird, and passerine assemblages (average ± standard error) per sampling event at mangrove and marsh sites in the lower study region.

3.2 Abundance and Simpson's Diversity Index

For 28 of the 36 sampling events in the central study region, birdwatchers recorded the number of birds present per species (marsh = 16, mangrove = 12). Average bird abundance was significantly lower in mangrove sites than in marshes ($p = 0.001$, Figure 11). In marsh sites, birdwatchers reported counts for 82 species. Shorebirds were the most abundant assemblage, though variability was relatively high (Figure 12). The three most abundant shorebird species observed within marshes were Least Sandpipers, Black-necked Stilts, and Western Sandpipers (Appendix Table A-5). In mangrove sites, birdwatchers reported counts for 32 species. Within mangroves, wading and shorebird assemblages had the highest abundances (Figure 12). The three wading species with the highest average abundance per sampling event were White Ibises, Cattle Egrets, and Great Egrets; the three shorebird species with the highest average abundance per sampling event were Willets, Ruddy Turnstones, and Long-billed Dowitchers (Appendix Table A-5). With the exception of Great-tailed Grackles, passerine abundance was low in mangroves (Figure 12, Appendix Table A-5). Simpson's diversity indices did not differ between central region mangrove and marsh sites ($p = 0.399$, Figure 13). However, this result may have been driven by the high variability amongst mangrove sampling events ($n = 12$) compared to marsh sampling events ($n = 16$, Figures 14A, 14C).

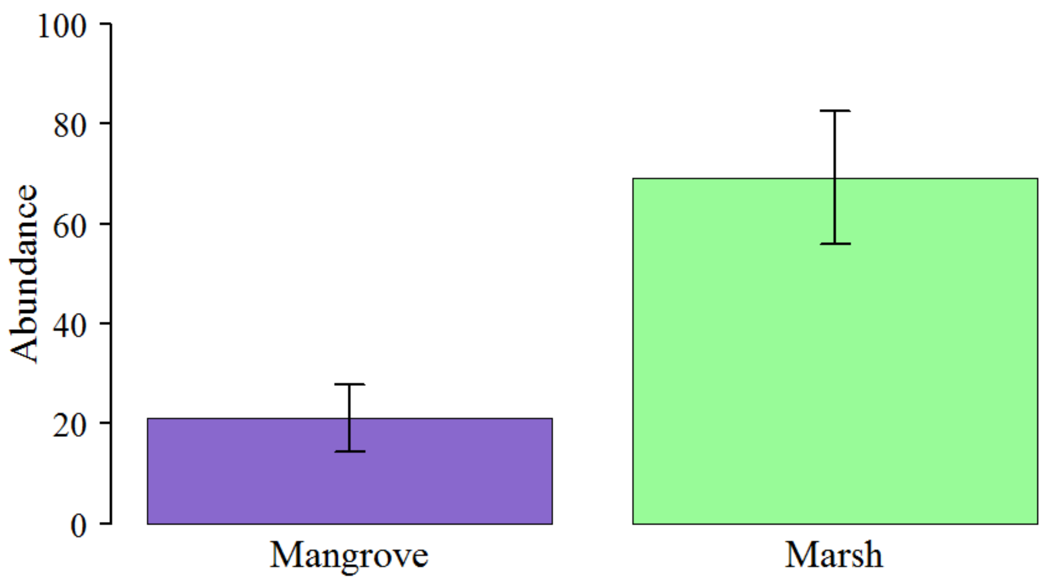

Figure 11. Bird abundance (average ± standard error) per sampling event at mangrove and marsh sites in the central region.

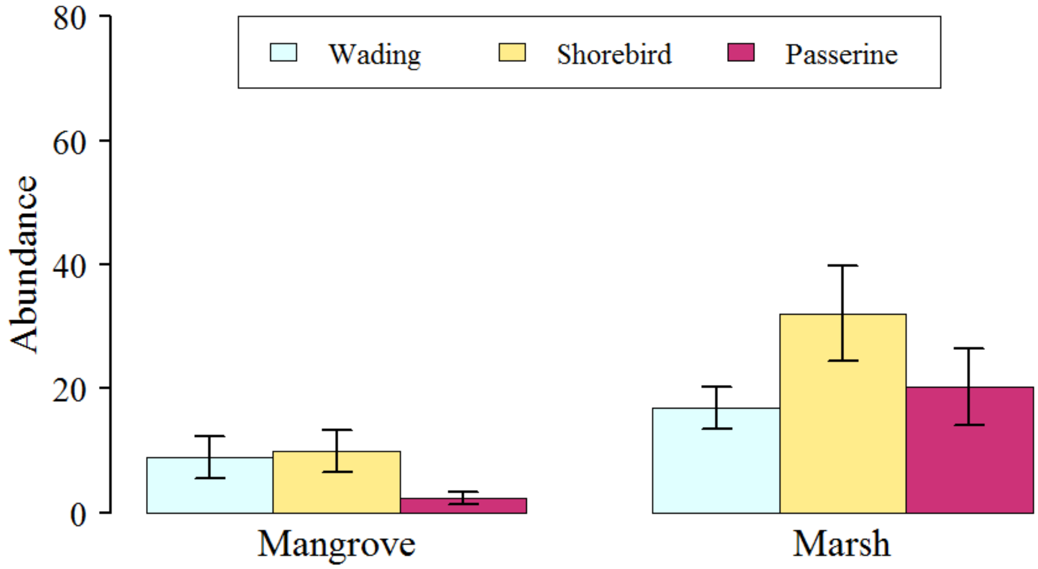

Figure 12. Bird abundance in wading, shorebird and passerine assemblages (average ± standard error) per sampling event at mangrove and marsh sites in the central study region.

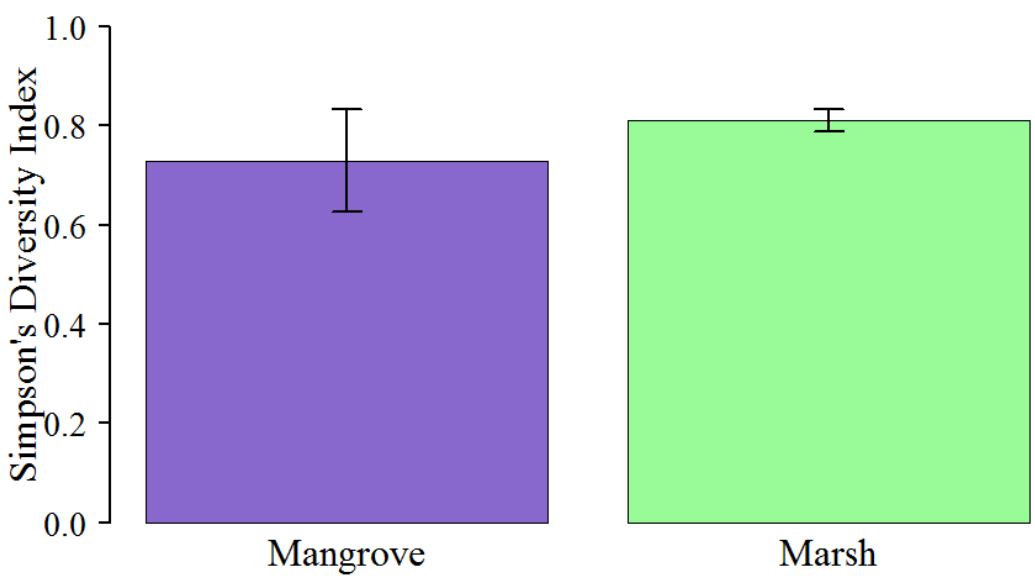

Figure 13. Simpson's Diversity Index (average ± standard error) per sampling event at mangrove and marsh sites in the central study region.

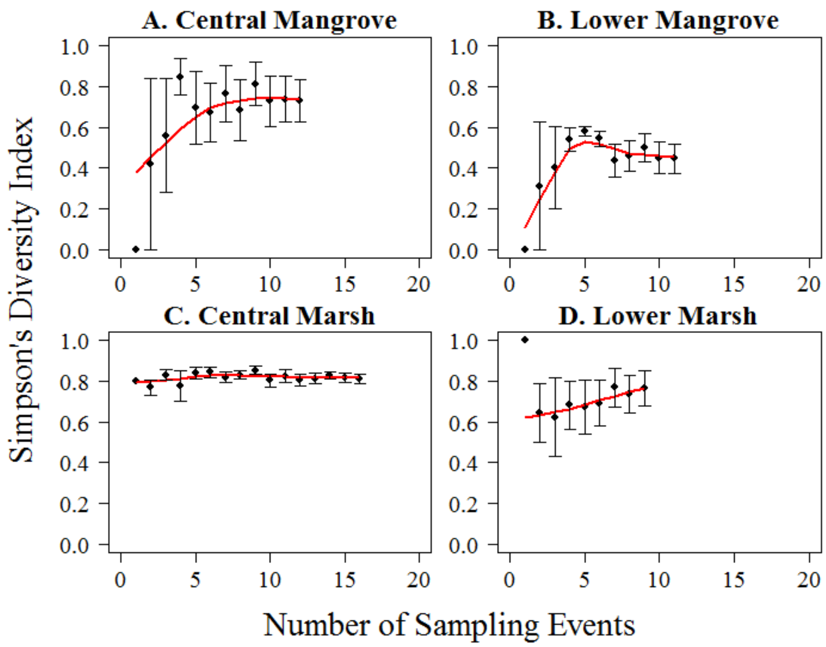

Figure 14. Sequential sample size analyses depicting the stability across the total number of Simpson's Diversity Indices sampling events (average ± standard error) for (A and C) central and (B and D) lower regions.

Birdwatchers recorded the abundance of observed bird species for 20 of the 25 sampling events in the lower region (marsh = 9, mangrove =11). Marsh sites had four times higher total bird abundance than mangrove sites, but was a marginally non-significant difference ($p = 0.057$, Figure 15) which may have been driven by high variability amongst marsh and mangrove sites (Figures 16B, 16D). Birdwatchers reported counts for 23 species within marsh sites; the three most abundant species per sampling event were all shorebird species, Marbled Godwit, Black-bellied Plover, and Willet (Appendix Table A-5). The shorebird assemblage had a qualitatively higher abundance than any other bird assemblage for the average marsh site sampling event

(Figure 17). In mangrove sites, birdwatchers reported counts for 19 species and the most abundant species per sampling event were Willets, Great-tailed Grackles, Long-billed Curlews, and Snowy Egrets (Appendix Table A-5). Wading and shorebird assemblages had the highest abundances for the average mangrove sampling event (Figure 17). Mangrove sites had significantly lower Simpson's diversity index than marshes (p = 0.007) (Figure 18).

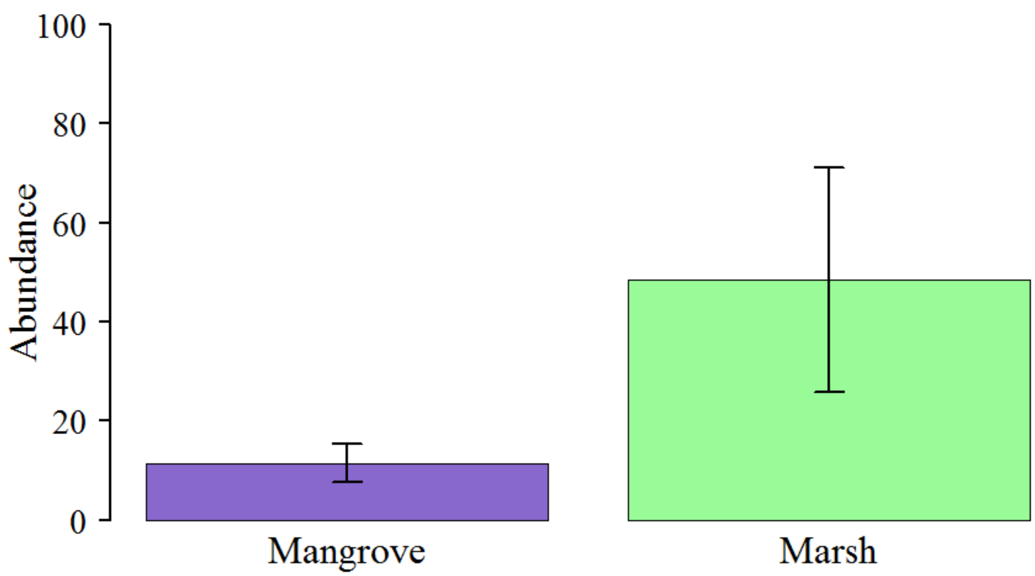

Figure 15. Bird abundance (average ± standard error) per sampling event at mangrove and marsh sites in the lower region.

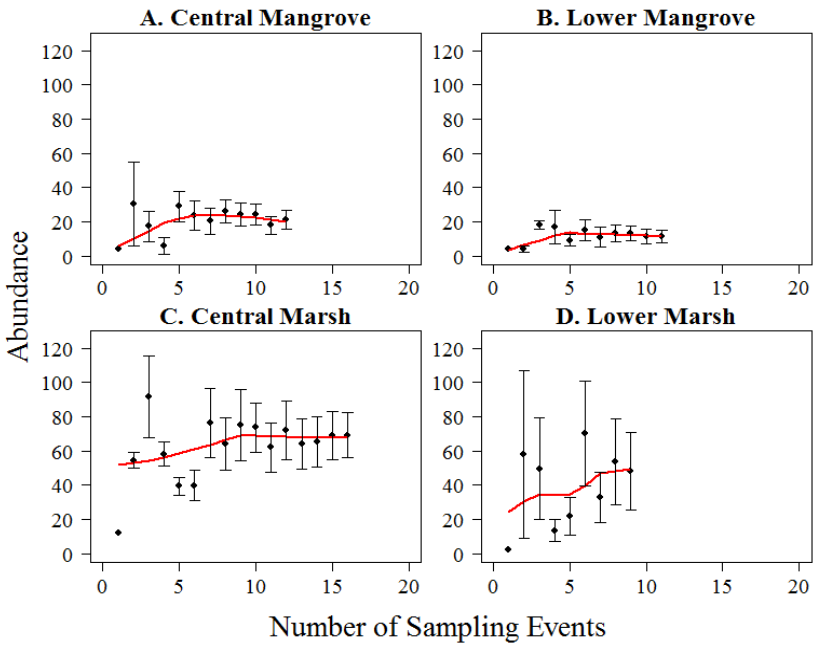

Figure 16. Sequential sample size analyses depicting the stability across the total number of abundance sampling events (average ± standard error) for (A and C) central and (B and D) lower regions.

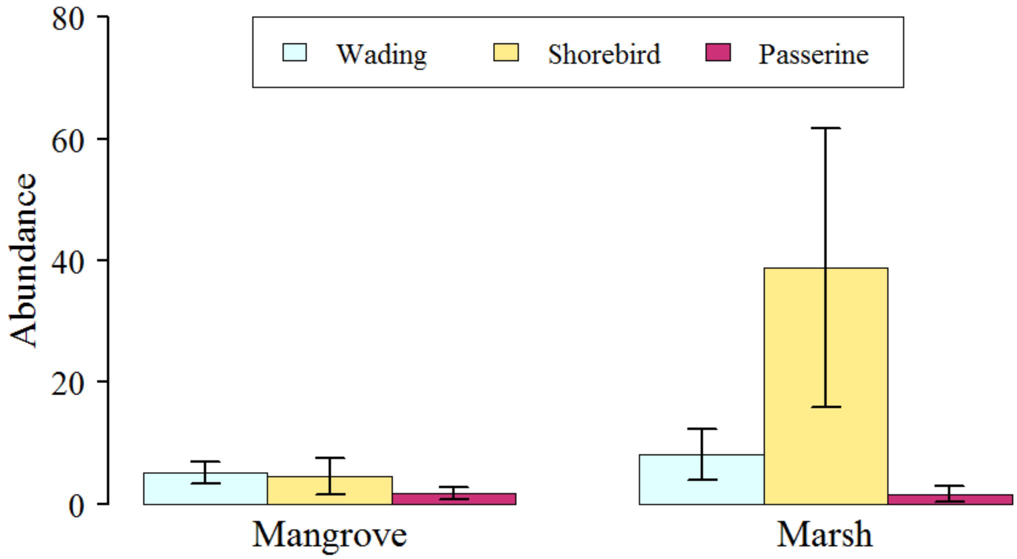

Figure 17. Bird abundance in wading, shorebird and passerine assemblages (average ± standard error) per sampling event at mangrove and marsh sites in the lower study region.

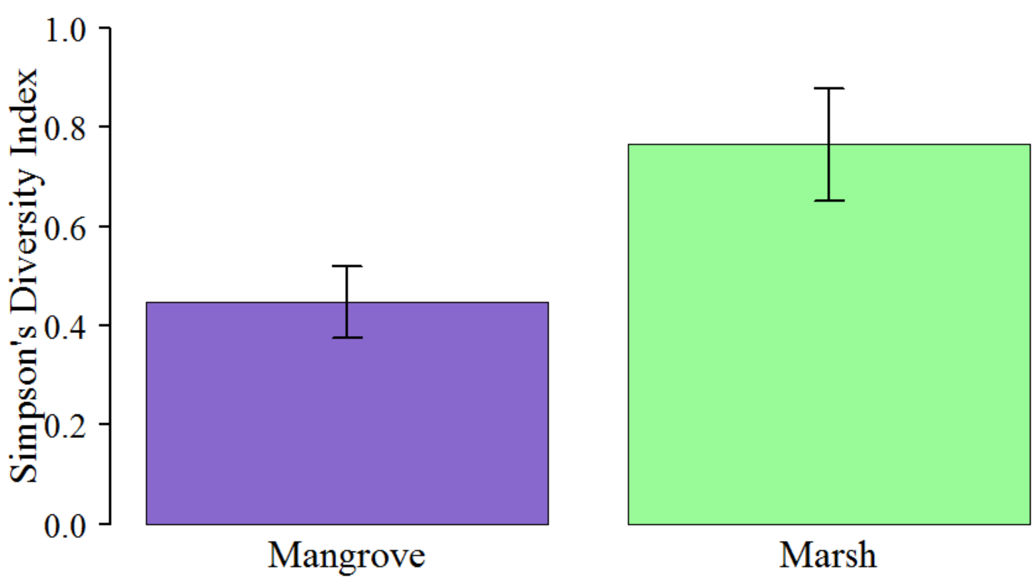

Figure 18. Simpson's Diversity Index (average ± standard error) per sampling event at mangrove and marsh sites in the lower study region.

3.3 Bird Community Composition

For mangrove and marsh sites in the central study region, bird species assemblages were dissimilar from each other but there was some overlap between vegetation types (ANOSIM, Global $R = 0.268$, $p = 0.002$, Figure 19). SIMPER analysis revealed that dissimilarity between vegetation types was not driven by any individual species, all bird species contributed fairly equally to the dissimilarity between vegetation types, 26 species individually contributed a small amount (<5%) to the cumulative dissimilarity (Table 2).

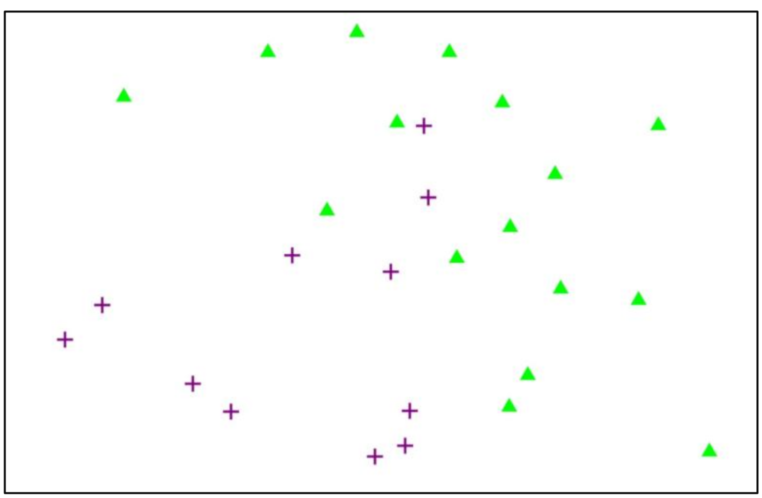

Figure 19. nMDS ordination of bird community composition based on species at central region sites, derived from a log-transformed Bray-Curtis similarity matrix (2D stress= 0.23). Symbols positioned closer to one another have more similar bird communities; (+) mangrove, (▲) marsh.

Table 1. The percent contribution of bird species to dissimilarities between mangrove and marsh sampling events in the central region. SIMPER analysis values are provided for species contributing up to 70% of the cumulative dissimilarity.

Species	Assemblage	Dissimilarity	
		% Contributed	% Cumulative
Roseate Spoonbill	Wading	5.23	5.23
Black-necked Stilt	Shorebird	4.81	10.04
Least Sandpiper	Shorebird	4.45	14.49
White Ibis	Wading	4.38	18.87
Great-tailed Grackle	Passerine	4.36	23.23
Great Egret	Wading	4.08	27.31
Willet	Shorebird	3.8	31.11
Great Blue Heron	Wading	3.24	34.36
Tricolored Heron	Wading	2.89	37.24
Long-billed Dowitcher	Shorebird	2.83	40.07
Western Sandpiper	Shorebird	2.69	42.76
Snowy Egret	Wading	2.65	45.41
Red-winged Blackbird	Passerine	2.61	48.02
Reddish Egret	Wading	2.4	50.41
American Avocet	Shorebird	2.33	52.75
Dunlin	Shorebird	2.31	55.06
Greater Yellowlegs	Shorebird	2.27	57.33
Ruddy Turnstone	Shorebird	2.02	59.35
Green Heron	Wading	1.78	61.13
Northern Mockingbird	Passerine	1.66	62.79
Cattle Egret	Wading	1.55	64.35
Dickcissel	Passerine	1.28	65.63
Short-billed Dowitcher	Shorebird	1.24	66.87
Northern Cardinal	Passerine	1.23	68.1
Black-bellied Plover	Shorebird	1.16	69.26
Yellow-rumped Warbler	Passerine	1.1	70.36

Wading, shorebird and passerine assemblages between mangrove and marsh sites in the central study region were significantly dissimilar from each other with some overlap (ANOSIM, Global R = 0.273, p = 0.001, Table 3). A 2D nMDS plot of collective assemblages shows that a few mangrove sampling events had distinctly different assemblages, and other mangrove and marsh sampling events overlapped (Figure 20).

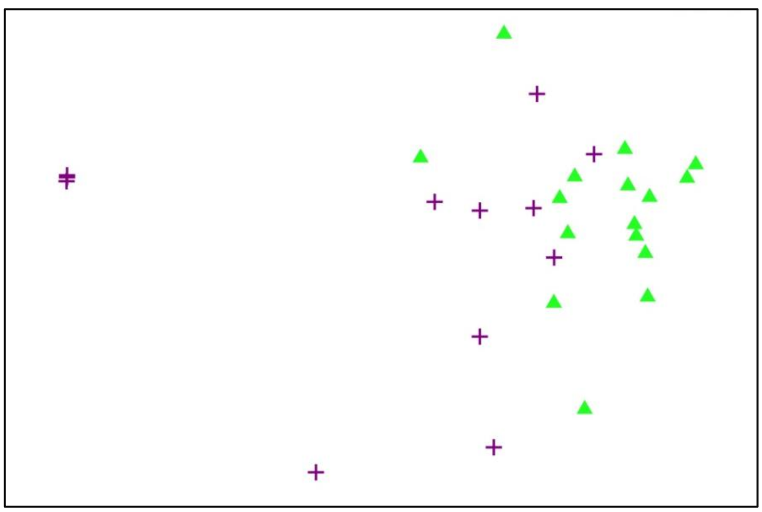

Figure 20. nMDS ordination of bird community composition based on wading, shorebird, and passerine assemblages at central region sites, derived from a log-transformed Bray-Curtis similarity matrix (2D stress= 0.13). Symbols positioned closer to one another have more similar bird communities; (+) mangrove, (▲) marsh.

SIMPER analysis of bird assemblages in the central region revealed that waders, shorebirds and passerines contributed relatively equally to the dissimilarity between mangrove and marsh sampling events (Table 3). To visualize the contribution of each bird assemblage to community level differences between vegetation types, I overlaid bubble plots of the abundances of each assemblage over the nMDS plot of community composition that was depicted in Figure 20. All three assemblages had higher abundances in marshes than in mangroves (Figures 21, 22, 23), but the larges disparities in abundance were apparent in the shorebird and passerine assemblages (Figures 22, 23).

Table 2. The percent contribution of wading, shorebird and passerine assemblages to dissimilarities between mangrove and marsh sampling events in the central region.

Assemblage	Dissimilarity	
	% Contributed	% Cumulative
Passerine	35.99	35.99
Shorebird	34.22	70.21
Wading	29.79	100

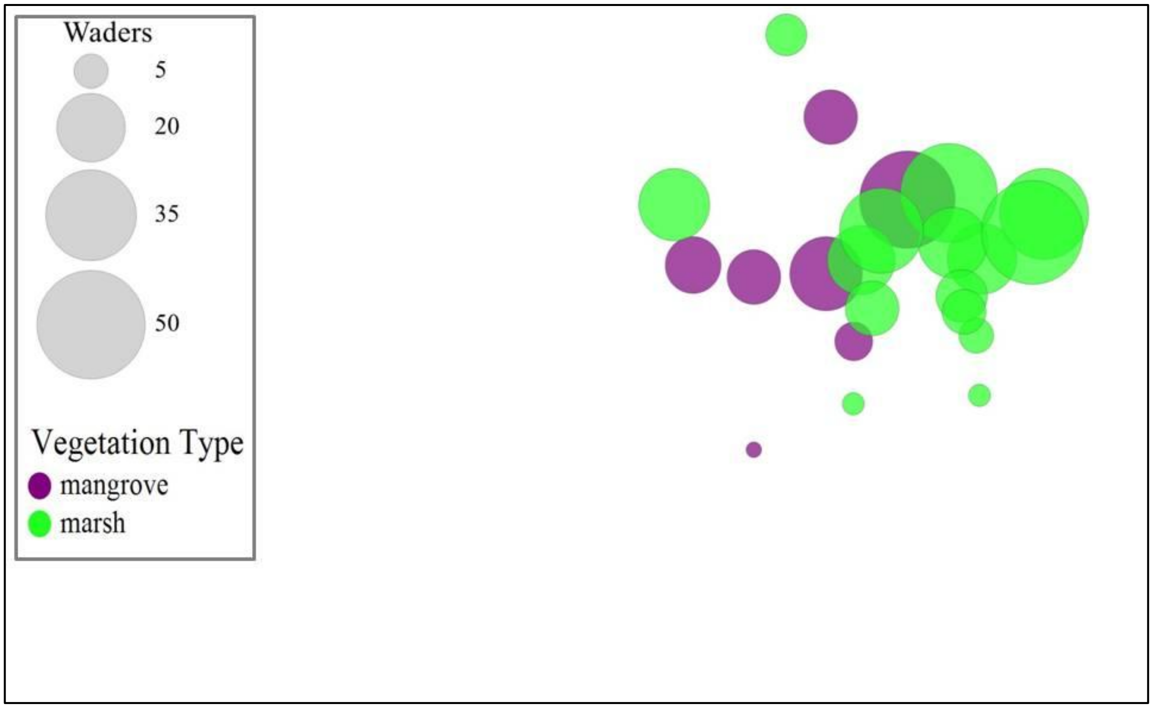

Figure 21. Bubble plots of wading bird abundance overlaid on nMDS ordination of bird community composition based on wading, shorebird, and passerine assemblages at central region sites, derived from a log-transformed Bray-Curtis similarity matrix (2D stress = 0.13). Symbols positioned closer to one another have more similar bird communities; circle size represents the relative abundance of waders.

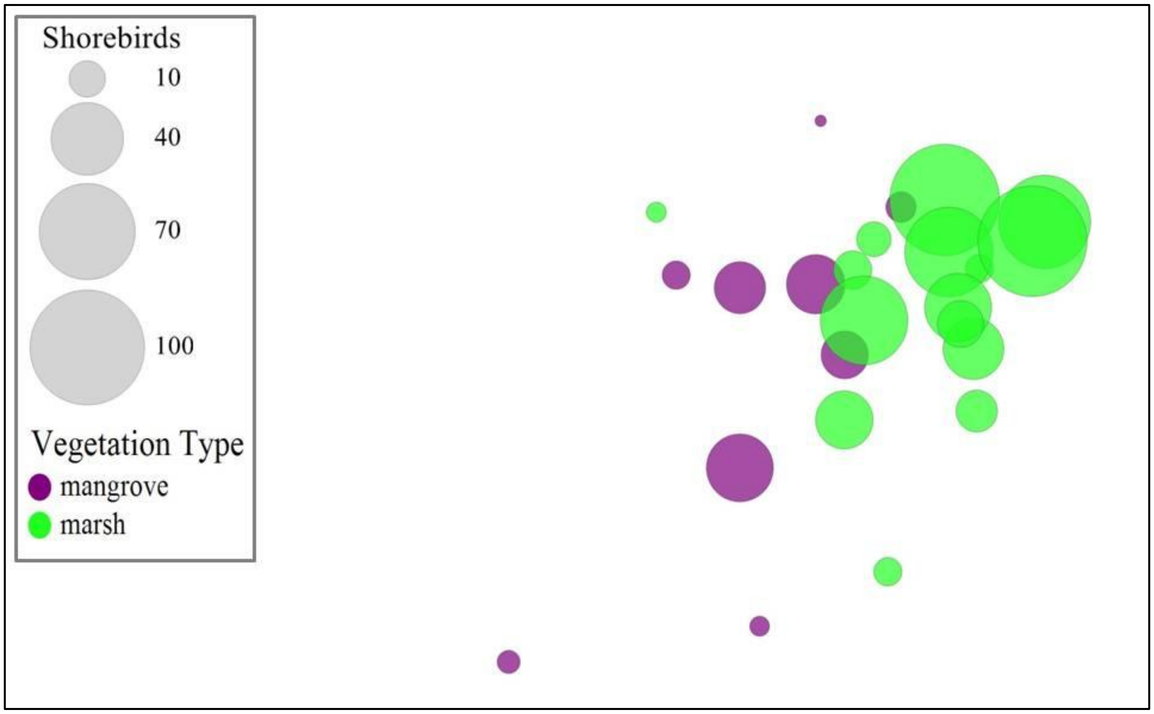

Figure 22. Bubble plots of shorebird abundance overlaid on nMDS ordination of bird community composition based on wading, shorebird, and passerine assemblages at central region sites, derived from log-transformed Bray-Curtis similarity matrix (2D stress = 0.13). Symbols positioned closer to one another have more similar bird communities; circle size represents the relative abundance of shorebirds.

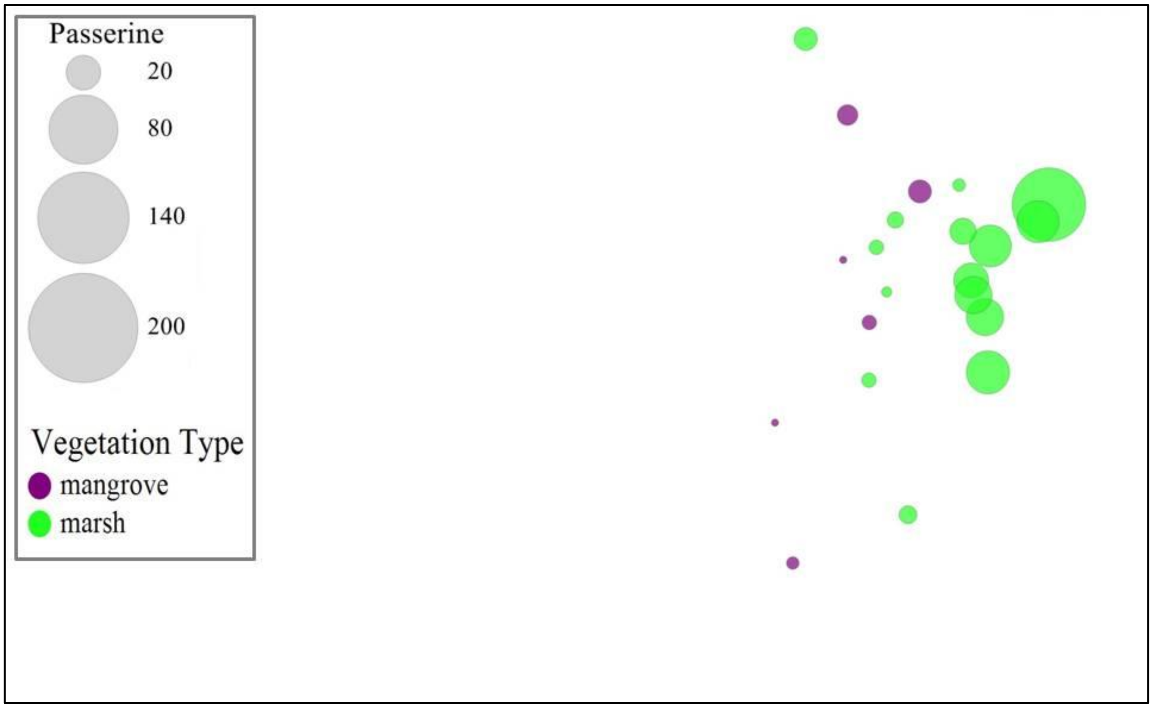

Figure 23. Bubble plots of passerine abundance overlaid on nMDS ordination of bird community composition based on wading, shorebird, and passerine assemblages at central region sites, derived from a log-transformed Bray-Curtis similarity matrix (2D stress = 0.13). Symbols positioned closer to one another have more similar bird communities; circle size represents the relative abundance of passerines.

The bird community compositions between vegetation types in the lower study region were not significantly dissimilar from one another (ANOSIM, Global R = 0.01, p = 0.394). Furthermore, the collective wading, shorebird, and passerine assemblages between vegetation types in the lower study region were not significantly dissimilar from one another (ANOSIM, Global R = 0.123, p = 0.09).

4. DISCUSSION AND CONCLUSIONS

Bird use differed between mangroves and marshes, but general patterns of use varied amongst study regions. In general, more bird species and higher abundances were observed in marshes than mangroves for either region. Diversity of bird species and community compositions were different in each of these vegetation types and regions. Bird diversity was significantly higher in lower region marshes than in mangroves; however, no dissimilarity in community composition were found in this region. In the central region, marshes and mangroves supported distinctly dissimilar bird communities at species and assemblage levels.

4.1 Waders

Waders were relatively abundant across all vegetation types and regions. Though more wader species were observed per sampling event in marshes than mangroves, the most commonly observed species were the same in both regions' vegetation types (Great Blue Herons, Great Egrets, and Snowy Egrets). Although there was some species overlap, marshes generally had higher wader abundances than mangroves, especially in the lower region. Wader preferences for marshes may be linked to the structural features of mangrove stands. Mangrove tree density can reduce wading bird density (Sandilyan and Kathiresan 2015). In addition, the spread of mangrove pneumatophores into mudflats, shallow canals, or ponds could alter areas where wading birds forage. Although alterations of wading bird foraging behavior have not yet been explicitly linked to mangrove pneumatophores, vegetation density can decrease the number of foraging waders (Bancroft et al. 2002), and it is likely that dense aggregations of pneumatophores may inhibit efficient foraging (Meyerriecks 1971). The effect is supported by this study, where Roseate Spoonbills and White Ibises, which are wading species that forage by using their bill to strain or probe, had somewhat higher abundances and reported frequency in central region marshes than in mangroves.

Little is understood about the effects of black mangrove expansion on coastal food webs in the Gulf of Mexico. A Louisiana field study found that structurally complex mangrove stands tended to support higher densities of small or juvenile crustaceans, whereas fish densities were generally higher in marshes (Caudill 2005). At Horn Island, Mississippi, an area which had been recently colonized by black mangroves, Schefell (2015) found higher abundances of nekton and infauna in mangrove-marsh mix than in marshes. It is likely that these differences in nekton and infauna will yield different levels of trophic support for wading birds, but wading bird foraging behavior and catch efficiency in mangrove stands within the Gulf of Mexico has not yet been quantified.

4.2 Shorebirds

Shorebirds were commonly observed everywhere except for the lower study region mangroves. Though the average bird abundance was marginally non-significant between vegetation types, bird diversity significantly differed between mangroves and marshes in the lower region. This difference in diversity was likely driven by large flocks of shorebirds, such as Marbled Godwits, that were observed on certain individual sampling events in the lower region marsh sites. Likewise, more shorebirds were observed in central region marshes than in mangroves; this difference in abundance was attributable to shorebird species that are commonly seen in large flocks (Least Sandpipers, Black-necked Stilts, and Western Sandpipers).

Although many of the differences between shorebird assemblages in marshes and mangroves were attributable to large flocks of a few species, it is likely that many less abundant shorebird species will also show a preference for marshes. Within expansive marshes, shorebirds prefer patches of non-vegetated substrate for foraging (Withers 2002, Darnell and Smith 2004). However, these open habitat features may be obscured within mature black mangroves. The few studies that have compared shorebird abundances between marsh and mangrove habitat types support this scenario. For example, a study conducted in Port Aransas, Texas, found that the number of wading birds and shorebirds decreased with increasing mangrove coverage (Guo et al. In review). Additionally, at an Australian restoration site, shorebirds returned to roost and forage at a mud flat once encroaching mangroves were cut-back (Straw and Saintilan 2005). Within Texas marshes, shorebirds prefer utilizing patches of non-vegetated exposed-substrate (Withers 2002, Darnell and Smith 2004). This study suggests shorebirds are less likely to find preferred open habitat features within mature black mangrove stands therefore their abundances were lower at mangrove sites.

4.3 Passerines

Passerines were relatively uncommon except in central region marshes. Passerine species that are generally targeted by birdwatchers, such as migratory warblers, were found more often in central region marshes than mangroves. However, the most common species were Great-tailed Grackles and Red-winged Blackbirds in both vegetation types and regions. Passerines were included in my analyses because there has been recent interest by local environmental agencies and public stakeholders in planting black mangroves to restore Neotropical migrant stop-over habitat. There are few birds that are mangrove specialists; rather long distant migrants, in particular warblers, opportunistically utilize mangroves along migration routes (Nagelkerken et al. 2008, Hogarth 2015). However, this study revealed that more Neotropical warbler species were observed in marsh sites rather than in mangrove sites. Understanding migratory bird vegetation preferences is complex because individual species resource requirements can vary geographically (Deppe and Rotenberry 2008). Globally, there are few studies that have compared Neotropical bird assemblages between coastal habitat matrixes, specifically black mangrove stands and salt marshes, and none from the Gulf of Mexico region. A study conducted in Belize found that black mangroves supported a higher species richness of non-breeding Neotropical passerines than salt marshes (Gómez-Montes and Bayly 2010). In the Neotropics, the majority of black mangrove leaves do not fall off during the dry season, thereby maintaining a humid microhabitat that is suitable for insects (Lefebvre and Poulin 1996, Marra and Holmes 2001). Therefore, insectivorous birds may prefer utilizing black mangrove stands rather than adjacent arid vegetation stands during periods of limited rainfall (Morton 1980, Lefebvre et al. 1992, Lefebvre and Poulin 1996, Marra and Holmes 2001). However, the physiognomy of Texas mangrove stands vary from tropical mangrove forests and information on insect communities residing in these stands is currently lacking. Future comparisons of migrating passerine bird utilizations of salt marshes and mangroves could include analyses of insectivore prey abundance.

4.4 Community Composition

Patterns of bird community composition were unique for each region and vegetation type. In the central region, bird community composition, whether based on both species or on wading, shorebird, and passerine assemblages, was distinctly different between marsh and mangrove vegetation types; this difference between vegetation types was not apparent in the lower region. Although many species were observed in either vegetation type, mangroves and marshes supported different community assemblages of birds, at least in the central study region. Waders were common in both vegetation types, but there were large flocks of few shorebird species in marshes and more passerine species in marshes. These difference were likely linked to the heterogeneity of habitat features within the marsh mosaic, and to the physiognomy of vegetation. Wading and shorebirds prefer microhabitat features such as bare substrate and shallow-water ponds and canals (Darnell and Smith 2004); these microhabitat types are likely to be more common and accessible in marshes than in mangroves. Furthermore, passerines are commonly associated with densely vegetated, high marsh habitat types (Darnell and

Smith 2004). The physical structure of vegetation (physiognomy) in a habitat is also influential in structuring bird community assemblages (MacArthur and MacArthur 1961, MacArthur et al. 1966). This study is the first of its kind in mangrove and marsh habitat types, but the results parallel terrestrial studies which have found that encroaching shrubs into grasslands altered bird community compositions (Pidgeon et al. 2001, Skowno and Bond 2003, Sirami and Monadjem 2012).

4.5 Citizen Science: Limitations and Applications

Datasets collected by citizen scientists have inherent biases which may have influenced these bird community analyses. Since the 100 m radius zones encircling the sample sites were not exclusively comprised of tidally influenced marsh or mangrove, birdwatchers may have observed birds in other land cover classes. Within a study site, a birdwatcher may have observed warblers utilizing high marsh shrubs or counted wading and shorebirds in tidal flats adjacent to the marsh or mangrove stands. Furthermore, mangrove stands could have lowered detection probability due to lower visibility in tall canopies relative to open grassland habitats. The average short stature of Texas black mangroves likely minimized the effect of this bias.

The advancement of citizen science and cyberinformatics can aid in understanding the effects of climate change on bird community compositions. Datasets like eBird make large geographic and temporal scale studies financially and logistically feasible (Kelling et al. 2009, Sullivan et al. 2009, Hochachka et al. 2012). Findings from traditionally designed surveys could be complemented by datasets collected from citizen science projects (Kelling et al. 2009, Dickinson et al. 2010). For instance, one way to address the study's incident-based small sample sizes would be to indicate ideal study sites for eBird participants to visit regularly. Of the suggested 'hotspot' birding locations listed on the eBird online platform, few encompass dominant mangrove stands, especially in the central region of this study. Researchers could suggest study sites or recruit a subset of citizen scientists to participate in a more complex study design, such as observing foraging behavior. In general, citizen science projects should maintain simple protocol designs since complex methodology tends to recruit fewer participants (Bonney et al. 2009). However, participation increases when birdwatchers knowingly contribute to a specific project (Thompson et al. 2007). Furthermore, incorporating citizen scientists can help fund studies since grant agencies favor science outreach initiatives and public involvement (Dickinson et al. 2012, McKinley et al. 2015). The number of peer reviewed scientific publications that have included or studied citizen science methods is growing as publically crowd-sourced datasets continue to expand (McKinley et al. 2015).

4.6 Conclusions

This study provided an initial comprehensive assessment of how bird community compositions differ between black mangrove stands and salt marshes along the Texas coastline. General patterns of bird use differed between mangrove and marshes but also varied between regions. Abundance of wading bird, shorebird, and passerine assemblages was higher in marshes than in mangroves, especially in the central study region. Mangroves and marshes supported different bird communities, which may be linked to differences between mangroves and marshes in terms of microhabitat features and prey abundance. The composition of mangrove-marsh ecotone in this region is rapidly changing, and future investigations comparing changes in bird communities over time would be valuable in understanding the ecological implications of this shift. Understanding how woody encroachment affects marshes will enhance the ability of coastal managers to preserve vital habitat utilized by coastal bird communities under climate change scenarios, as well as maintain a thriving ecotourism industry that is based on diverse coastal bird assemblages.

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APPENDIX

Table A-1. Required information reported from eBird protocols.

	Observation Date	Duration (minutes)	Effort Area	Location	All Species Reported (Yes or No)
Casual Observation	Required	Not required (Assumed to last 10 min.)	Not required	Required	Required
Stationary Count	Required	Required	Remain within a 30 m area	Required	Required
Exhaustive Area Count	Required	Required	Report area searched (hectare)	Required	Required
Traveling Count	Required	Required	Report distance traveled (kilometer)	Required	Required

Table A-2. Number of sampling events for each region's estimated species richness data.

	Number of Sampling Events	Duration (min.)*	Number of Events Per Protocol Type				Number of Events within each Season**			
			Casual Observation	Stationary Count	Exhaustive Area Count	Traveling Count	Winter	Spring	Summer	Fall
Central Marsh	20	374	10	8	2	0	0	11	5	4
Central Mangrove	16	323	7	4	4	1	2	10	1	3
Lower Marsh	11	220	4	7	0	0	3	3	0	5
Lower Mangrove	14	247	5	9	0	0	3	6	1	4

* Assumed all sampling events that followed the Casual Observation protocol lasted for 10 minutes.

** Seasons were designated as Winter (December- February), Spring (March- May), Summer (June-August), and Fall (September - November).

Table A-3. Number of sampling events for each region's abundance and Simpson's diversity index.

	Number of Sampling Events	Duration (min.)*	Number of Events Per Protocol Type				Number of Events within each Season**			
			Casual Observation	Stationary Count	Exhaustive Area Count	Traveling Count	Winter	Spring	Summer	Fall
Central Marsh	16	274	9	6	1	0	0	9	4	3
Central Mangrove	12	233	4	4	3	1	2	7	1	2
Lower Marsh	9	200	2	7	0	0	3	2	0	4
Lower Mangrove	11	217	2	9	0	0	3	3	1	4

* Assumed all sampling events that followed the Casual Observation protocol lasted for 10 minutes.

** Seasons were designated as Winter (December- February), Spring (March- May), Summer (June-August), and Fall (September - November).

Table A-4. Percent frequency of occurrence of bird species in central and lower region vegetation types.

Common Name	Scientific Name	Assemblage	Percent Frequency			
			Central Mangrove	Central Marsh	Lower Mangrove	Lower Marsh
Black-crowned Night-Heron	*Nycticorax nycticorax*	Wading	6.3	10.0	--	18.2
Cattle Egret	*Bubulcus ibis*	Wading	12.5	15.0	7.1	18.2
Great Blue Heron	*Ardea herodias*	Wading	31.3	65.0	42.9	72.7
Great Egret	*Ardea alba*	Wading	31.3	55.0	42.9	63.6
Green Heron	*Butorides virescens*	Wading	6.3	35.0	7.1	--
Least Bittern	*Ixobrychus exilis*	Wading	--	10.0	--	--
Little Blue Heron	*Egretta caerulea*	Wading	12.5	15.0	28.6	27.3
Reddish Egret	*Egretta rufescens*	Wading	50.0	35.0	28.6	18.2
Roseate Spoonbill	*Platalea ajaja*	Wading	25.0	60.0	21.4	18.2
Snowy Egret	*Egretta thula*	Wading	31.3	45.0	28.6	63.6
Tricolored Heron	*Egretta tricolor*	Wading	12.5	50.0	21.4	54.5
White Ibis	*Eudocimus albus*	Wading	25.0	50.0	28.6	27.3
White-faced Ibis	*Plegadis chihi*	Wading	--	--	7.1	--
Wood Stork	*Mycteria americana*	Wading	--	10.0	--	--
Yellow-crowned Night- Heron	*Nyctanassa violacea*	Wading	--	5.0	7.1	18.2
American Avocet	*Recurvirostra americana*	Shorebird	12.5	20.0	--	18.2
American Golden- Plover	*Pluvialis dominica*	Shorebird	--	5.0	--	--
American Oystercatcher	*Haematopus palliatus*	Shorebird	6.3	--	14.3	27.3
Baird's Sandpiper	*Calidris bairdii*	Shorebird	--	10.0	--	--
Black-bellied Plover	*Pluvialis squatarola*	Shorebird	37.5	10.0	7.1	54.5
Black-necked Stilt	*Himantopus mexicanus*	Shorebird	12.5	60.0	7.1	36.4

Table A-4 Continued

Common Name	Scientific Name	Assemblage	Percent Frequency			
			Central Mangrove	Central Marsh	Lower Mangrove	Lower Marsh
Dunlin	*Calidris alpina*	Shorebird	12.5	25.0	--	27.3
Greater Yellowlegs	*Tringa melanoleuca*	Shorebird	12.5	40.0	7.1	27.3
Unidentified Yellowlegs	*Tringa* spp.	Shorebird	--	5.0	--	--
Killdeer	*Charadrius vociferus*	Shorebird	--	15.0	--	9.1
Least Sandpiper	*Calidris minutilla*	Shorebird	18.8	40.0	--	9.1
Lesser Yellowlegs	*Tringa flavipes*	Shorebird	--	25.0	--	18.2
Long-billed Curlew	*Numenius americanus*	Shorebird	12.5	10.0	14.3	27.3
Long-billed Dowitcher	*Limnodromus scolopaceus*	Shorebird	18.8	20.0	--	--
Marbled Godwit	*Limosa fedoa*	Shorebird	6.3	--	--	27.3
Pectoral Sandpiper	*Calidris melanotos*	Shorebird	--	10.0	--	--
Unidentified Sandpiper	*Calidris* spp.	Shorebird	--	5.0	--	--
Piping Plover	*Charadrius melodus*	Shorebird	12.5	--	--	9.1
Ruddy Turnstone	*Arenaria interpres*	Shorebird	18.8	5.0	7.1	45.5
Sanderling	*Calidris alba*	Shorebird	12.5	--	7.1	9.1
Semipalmated Plover	*Charadrius semipalmatus*	Shorebird	12.5	10.0	--	36.4
Semipalmated Sandpiper	*Calidris pusilla*	Shorebird	6.3	15.0	--	9.1
Short-billed Dowitcher	*Limnodromus griseus*	Shorebird	6.3	15.0	--	9.1
Unidentified Dowitcher	*Limnodromus* spp.	Shorebird	--	10.0	--	--
Snowy Plover	*Charadrius nivosus*	Shorebird	--	5.0	--	--
Solitary Sandpiper	*Tringa solitaria*	Shorebird	--	--	--	9.1
Spotted Sandpiper	*Actitis macularius*	Shorebird	6.3	5.0	7.1	9.1
Stilt Sandpiper	*Calidris himantopus*	Shorebird	--	10.0	--	18.2

Table A-4 Continued

Common Name	Scientific Name	Assemblage	Percent Frequency			
			Central Mangrove	Central Marsh	Lower Mangrove	Lower Marsh
Western Sandpiper	*Calidris mauri*	Shorebird	6.3	25.0	--	18.2
Whimbrel	*Numenius phaeopus*	Shorebird	--	--	7.1	--
White-rumped Sandpiper	*Calidris fuscicollis*	Shorebird	--	10.0	--	--
Willet	*Tringa semipalmata*	Shorebird	56.3	45.0	14.3	63.6
Wilson's Phalarope	*Phalaropus tricolor*	Shorebird	--	10.0	--	--
Wilson's Plover	*Charadrius wilsonia*	Shorebird	--	5.0	7.1	9.1
Altamira Oriole	*Icterus gularis*	Passerine	--	--	7.1	--
American Redstart	*Setophaga ruticilla*	Passerine	--	5.0	--	--
Baltimore Oriole	*Icterus galbula*	Passerine	--	10.0	--	--
Black-and-white Warbler	*Mniotilta varia*	Passerine	--	5.0	7.1	--
Blackburnian Warbler	*Setophaga fusca*	Passerine	--	5.0	--	--
Blue Grosbeak	*Passerina caerulea*	Passerine	--	5.0	--	--
Bronzed Cowbird	*Molothrus aeneus*	Passerine	--	--	7.1	--
Unidentified Cowbird	*Molothrus* spp.	Passerine	--	5.0	--	--
Brown-headed Cowbird	*Molothrus ater*	Passerine	6.3	5.0	7.1	--
Canada Warbler	*Cardellina canadensis*	Passerine	--	5.0	--	--
Cape May Warbler	*Setophaga tigrina*	Passerine	--	5.0	--	--
Chestnut-sided Warbler	*Setophaga pensylvanica*	Passerine	--	5.0	--	--
Chipping Sparrow	*Spizella passerina*	Passerine	--	5.0	--	--
Common Yellowthroat	*Geothlypis trichas*	Passerine	--	10.0	--	--
Couch's Kingbird	*Tyrannus couchii*	Passerine	--	5.0	--	--
Dickcissel	*Spiza americana*	Passerine	--	10.0	--	--

Table A-4 Continued

Common Name	Scientific Name	Assemblage	Percent Frequency			
			Central Mangrove	Central Marsh	Lower Mangrove	Lower Marsh
Eastern Kingbird	*Tyrannus tyrannus*	Passerine	--	15.0	--	--
Eastern Wood- Pewee	*Contopus virens*	Passerine	--	10.0	--	--
Empidonax spp.	*Empidonax* spp.	Passerine	--	5.0	--	--
European Starling	*Sturnus vulgaris*	Passerine	--	5.0	--	--
Gray Catbird	*Dumetella carolinensis*	Passerine	--	5.0	--	--
Great Kiskadee	*Pitangus sulphuratus*	Passerine	--	--	7.1	--
Great-tailed Grackle	*Quiscalus mexicanus*	Passerine	37.5	50.0	21.4	36.4
Green Jay	*Cyanocorax yncas*	Passerine	--	--	7.1	--
Hooded Warbler	*Setophaga citrina*	Passerine	--	10.0	7.1	--
Horned Lark	*Eremophila alpestris*	Passerine	--	10.0	--	--
House Sparrow	*Passer domesticus*	Passerine	--	15.0	--	9.1
Indigo Bunting	*Passerina cyanea*	Passerine	--	--	7.1	--
Loggerhead Shrike	*Lanius ludovicianus*	Passerine	--	10.0	--	--
Long-billed Thrasher	*Toxostoma longirostre*	Passerine	--	--	7.1	--
Magnolia Warbler	*Setophaga magnolia*	Passerine	--	5.0	--	--
Marsh Wren	*Cistothorus palustris*	Passerine	--	5.0	--	--
Northern Cardinal	*Cardinalis cardinalis*	Passerine	--	25.0	--	--
Northern Mockingbird	*Mimus polyglottos*	Passerine	6.3	45.0	--	9.1
Northern Waterthrush	*Parkesia noveboracensis*	Passerine	--	5.0	--	--
Olive Sparrow	*Arremonops rufivirgatus*	Passerine	--	5.0	--	--
Orchard Oriole	*Icterus spurius*	Passerine	--	5.0	--	--
Painted Bunting	*Passerina ciris*	Passerine	--	5.0	--	--

Table A-4 Continued

Common Name	Scientific Name	Assemblage	Percent Frequency			
			Central Mangrove	Central Marsh	Lower Mangrove	Lower Marsh
Prothonotary Warbler	*Protonotaria citrea*	Passerine	--	--	7.1	--
Red-eyed Vireo	*Vireo olivaceus*	Passerine	--	5.0	--	--
Red-winged Blackbird	*Agelaius phoeniceus*	Passerine	12.5	45.0	7.1	18.2
Ruby-crowned Kinglet	*Regulus calendula*	Passerine	--	5.0	--	9.1
Savannah Sparrow	*Passerculus sandwichensis*	Passerine	6.3	5.0	--	9.1
Scissor-tailed Flycatcher	*Tyrannus forficatus*	Passerine	--	25.0	14.3	--
Sedge Wren	*Cistothorus platensis*	Passerine	--	--	--	9.1
Swamp Sparrow	*Melospiza georgiana*	Passerine	--	5.0	--	--
Tennessee Warbler	*Oreothlypis peregrina*	Passerine	--	10.0	--	--
Tropical Kingbird	*Tyrannus melancholicus*	Passerine	--	--	--	9.1
Willow Flycatcher	*Empidonax traillii*	Passerine	--	5.0	--	--
Wilson's Warbler	*Cardellina pusilla*	Passerine	--	--	7.1	--
Yellow Warbler	*Setophaga petechia*	Passerine	--	20.0	7.1	--
Yellow-rumped Warbler	*Setophaga coronata*	Passerine	--	10.0	7.1	--
Yellow-throated Warbler	*Setophaga dominica*	Passerine	--	5.0	7.1	--

Table A-5. Average abundance and standard error of bird species per sampling event and their allocated assemblage in central and lower region vegetation types.

			Mean ± SE			
Common Name	Scientific Name	Assemblage	Central Mangrove	Central Marsh	Lower Mangrove	Lower Marsh
Black-crowned Night-Heron	*Nycticorax nycticorax*	Wading	0.08 ± 0.08	0.19 ± 0.14	--	--
Cattle Egret	*Bubulcus ibis*	Wading	1.42 ± 1.33	1.56 ± 1.56	--	0.67 ± 0.55
Great Blue Heron	*Ardea herodias*	Wading	0.92 ± 0.47	1.92 ± 0.86	0.64 ± 0.31	0.89 ± 0.35
Great Egret	*Ardea alba*	Wading	1.25 ± 0.71	1.63 ± 0.91	0.45 ± 0.21	2 ± 1.2
Green Heron	*Butorides virescens*	Wading	0.08 ± 0.08	0.81 ± 0.38	--	--
Least Bittern	*Ixobrychus exilis*	Wading	--	0.13 ± 0.09	--	--
Little Blue Heron	*Egretta caerulea*	Wading	0.08 ± 0.08	0.31 ± 0.22	0.18 ± 0.12	0.22 ± 0.15
Reddish Egret	*Egretta rufescens*	Wading	1.17 ± 0.65	0.56 ± 0.18	0.64 ± 0.39	0.22 ± 0.22
Roseate Spoonbill	*Platalea ajaja*	Wading	0.75 ± 0.51	3.88 ± 1.45	0.18 ± 1.09	--
Snowy Egret	*Egretta thula*	Wading	0.92 ± 0.42	1 ± 0.4	1 ± 0.59	0.89 ± 0.42
Tricolored Heron	*Egretta tricolor*	Wading	0.25 ± 0.18	1.5 ± 0.52	0.27 ± 0.19	0.78 ± 0.46
White Ibis	*Eudocimus albus*	Wading	2 ± 1.29	3.13 ± 1.34	0.64 ± 0.31	1.11 ± 0.81
White-faced Ibis	*Plegadis chihi*	Wading	--	--	0.18 ± 0.18	--
Wood Stork	*Mycteria americana*	Wading	--	0.25 ± 0.17	--	--
Yellow-crowned Night- Heron	*Nyctanassa violacea*	Wading	--	0.06 ± 0.06	--	1.33 ± 1.33
American Avocet	*Recurvirostra americana*	Shorebird	--	2.75 ± 1.62	--	--
American Golden- Plover	*Pluvialis dominica*	Shorebird	--	0.06 ± 0.06	--	--
American Oystercatcher	*Haematopus palliatus*	Shorebird	0.25 ± 0.25	--	0.18 ± 0.18	0.44 ± 0.29
Baird's Sandpiper	*Calidris bairdii*	Shorebird	--	0.13 ± 0.09	--	--
Black-bellied Plover	*Pluvialis squatarola*	Shorebird	0.33 ± 0.14	0.13 ± 0.09	0.27 ± 0.27	3.89 ± 2.75
Black-necked Stilt	*Himantopus mexicanus*	Shorebird	0.5 ± 0.36	3.69 ± 1.52	--	2.22 ± 2.22

Table A-5 Continued

Common Name	Scientific Name	Assemblage	Mean ± SE			
			Central Mangrove	Central Marsh	Lower Mangrove	Lower Marsh
Dunlin	*Calidris alpina*	Shorebird	1.08 ± 1	1.69 ± 0.8	--	2.22 ± 2.22
Greater Yellowlegs	*Tringa melanoleuca*	Shorebird	0.17 ± 0.11	0.81 ± 0.29	0.18 ± 0.18	0.44 ± 0.34
Unidentified Yellowlegs	*Tringa* spp.	Shorebird	--	0.06 ± 0.06	--	--
Killdeer	*Charadrius vociferus*	Shorebird	--	0.19 ± 0.1	--	--
Least Sandpiper	*Calidris minutilla*	Shorebird	0.58 ± 0.42	9.25 ± 4.39	--	--
Lesser Yellowlegs	*Tringa flavipes*	Shorebird	--	0.88 ± 0.51	--	--
Long-billed Curlew	*Numenius americanus*	Shorebird	0.25 ± 0.18	0.13 ± 0.09	1.36 ± 1.36	0.22 ± 0.22
Long-billed Dowitcher	*Limnodromus*	Shorebird	1.17 ± 0.64	1.5 ± 0.94	--	--
Marbled Godwit	*Limosa fedoa*	Shorebird	--	--	--	22.22 ± 22.22
Pectoral Sandpiper	*Calidris melanotos*	Shorebird	--	0.31 ± 0.25	--	--
Unidentified Sandpiper	*Calidris* spp.	Shorebird	--	1.56 ± 1.56	--	--
Piping Plover	*Charadrius melodus*	Shorebird	0.17 ± 0.11	--	--	--
Ruddy Turnstone	*Arenaria interpres*	Shorebird	1.58 ± 1	0.25 ± 0.25	--	0.11 ± 0.11
Sanderling	*Calidris alba*	Shorebird	0.5 ± 0.42	--	--	--
Semipalmated Plover	*Charadrius semipalmatus*	Shorebird	0.75 ± 0.66	0.19 ± 0.13	--	0.44 ± 0.34
Semipalmated Sandpiper	*Calidris pusilla*	Shorebird	0.08 ± 0.08	0.56 ± 0.45	--	--
Short-billed Dowitcher	*Limnodromus griseus*	Shorebird	0.5 ± 0.5	0.56 ± 0.44	--	--
Unidentified Dowitcher	*Limnodromus* spp.	Shorebird	--	0.56 ± 0.5	--	--
Snowy Plover	*Charadrius nivosus*	Shorebird	--	0.06 ± 0.06	--	--
Solitary Sandpiper	*Tringa solitaria*	Shorebird	--	--	--	0.11 ± 0.11
Spotted Sandpiper	*Actitis macularius*	Shorebird	0.08 ± 0.08	--	0.09 ± 0.09	0.11 ± 0.11

Table A-5 Continued

Common Name	Scientific Name	Assemblage	Mean ± SE			
			Central Mangrove	Central Marsh	Lower Mangrove	Lower Marsh
Stilt Sandpiper	*Calidris himantopus*	Shorebird	--	1.06 ± 0.9	--	0.11 ± 0.11
Western Sandpiper	*Calidris mauri*	Shorebird	--	3.5 ± 1.77	--	--
Whimbrel	*Numenius phaeopus*	Shorebird	--	--	0.09 ± 0.09	--
White-rumped Sandpiper	*Calidris fuscicollis*	Shorebird	--	0.69 ± 0.62	--	--
Willet	*Tringa semipalmata*	Shorebird	1.83 ± 0.46	1.19 ± 0.48	2.27 ± 2.27	6.22 ± 4.92
Wilson's Phalarope	*Phalaropus tricolor*	Shorebird	--	0.19 ± 0.14	--	--
Wilson's Plover	*Charadrius wilsonia*	Shorebird	--	0.13 ± 0.13	0.09 ± 0.09	--
American Redstart	*Setophaga ruticilla*	Passerine	--	0.06 ± 0.06	--	--
Baltimore Oriole	*Icterus galbula*	Passerine	--	0.69 ± 0.62	--	--
Black-and-white Warbler	*Mniotilta varia*	Passerine	--	0.06 ± 0.06	--	--
Blackburnian Warbler	*Setophaga fusca*	Passerine	--	0.06 ± 0.06	--	--
Blue Grosbeak	*Passerina caerulea*	Passerine	--	0.06 ± 0.06	--	--
Unidentified Cowbird	*Molothrus* spp.	Passerine	--	3.13 ± 3.13	--	--
Brown-headed Cowbird	*Molothrus ater*	Passerine	0.08 ± 0.08	0.19 ± 0.19	--	--
Canada Warbler	*Cardellina canadensis*	Passerine	--	0.06 ± 0.06	--	--
Cape May Warbler	*Setophaga tigrina*	Passerine	--	0.06 ± 0.06	--	--
Chestnut-sided Warbler	*Setophaga pensylvanica*	Passerine	--	0.06 ± 0.06	--	--
Chipping Sparrow	*Spizella passerina*	Passerine	--	0.19 ± 0.19	--	--
Common Yellowthroat	*Geothlypis trichas*	Passerine	--	0.19 ± 0.14	--	--
Dickcissel	*Spiza americana*	Passerine	--	1.69 ± 1.5	--	--
Eastern Kingbird	*Tyrannus tyrannus*	Passerine	--	0.38 ± 0.26	--	--
Eastern Wood- Pewee	*Contopus virens*	Passerine	--	0.19 ± 0.14	--	--

Table A-5 Continued

Common Name	Scientific Name	Assemblage	Mean ± SE Central Mangrove	Central Marsh	Lower Mangrove	Lower Marsh
Empidonax spp.	*Empidonax* spp.	Passerine	--	0.06 ± 0.06	--	--
European Starling	*Sturnus vulgaris*	Passerine	--	0.31 ± 0.31	--	--
Gray Catbird	*Dumetella carolinensis*	Passerine	--	0.06 ± 0.06	--	--
Great-tailed Grackle	*Quiscalus mexicanus*	Passerine	1.58 ± 0.86	5.06 ± 3.12	1.55 ± 1.06	1.56 ± 1.32
Hooded Warbler	*Setophaga citrina*	Passerine	--	0.06 ± 0.06	--	--
Horned Lark	*Eremophila alpestris*	Passerine	--	0.19 ± 0.19	--	--
House Sparrow	*Passer domesticus*	Passerine	--	0.44 ± 0.33	--	--
Loggerhead Shrike	*Lanius ludovicianus*	Passerine	--	0.13 ± 0.09	--	--
Magnolia Warbler	*Setophaga magnolia*	Passerine	--	0.25 ± 0.25	--	--
Marsh Wren	*Cistothorus palustris*	Passerine	--	0.19 ± 0.19	--	--
Northern Cardinal	*Cardinalis cardinalis*	Passerine	--	0.5 ± 0.22	--	--
Northern Mockingbird	*Mimus polyglottos*	Passerine	0.08 ± 0.08	0.75 ± 0.27	--	--
Northern Waterthrush	*Parkesia noveboracensis*	Passerine	--	0.38 ± 0.38	--	--
Olive Sparrow	*Arremonops rufivirgatus*	Passerine	--	0.06 ± 0.06	--	--
Orchard Oriole	*Icterus spurius*	Passerine	--	0.38 ± 0.38	--	--
Painted Bunting	*Passerina ciris*	Passerine	--	0.13 ± 0.13	--	--
Red-eyed Vireo	*Vireo olivaceus*	Passerine	--	0.19 ± 0.19	--	--
Red-winged Blackbird	*Agelaius phoeniceus*	Passerine	0.33 ± 0.33	1.13 ± 0.48	--	--
Ruby-crowned Kinglet	*Regulus calendula*	Passerine	--	0.63 ± 0.63	--	--
Savannah Sparrow	*Passerculus*	Passerine	0.17 ± 0.17	0.19 ± 0.19	--	--
Scissor-tailed Flycatcher	*Tyrannus forficatus*	Passerine	--	0.38 ± 0.26	0.18 ± 0.18	--
Swamp Sparrow	*Melospiza georgiana*	Passerine	--	0.13 ± 0.13	--	--

Table A-5 Continued

Common Name	Scientific Name	Assemblage	Mean ± SE Central Mangrove	 Central Marsh	 Lower Mangrove	 Lower Marsh
Tennessee Warbler	*Oreothlypis peregrina*	Passerine	--	0.19 ± 0.14	--	--
Willow Flycatcher	*Empidonax traillii*	Passerine	--	0.06 ± 0.06	--	--
Yellow Warbler	*Setophaga petechia*	Passerine	--	0.63 ± 0.39	--	--
Yellow-rumped Warbler	*Setophaga coronata*	Passerine	--	0.69 ± 0.62	--	--
Yellow-throated Warbler	*Setophaga dominica*	Passerine	--	0.06 ± 0.06	--	--